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THE MODERN ASPHALT PAVEMENT

BY

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SECOND EDITION, REVISED AND ENLARGED
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PREFACE TO FIRST EDITION.

THE present work being designed for a rather wide class of readers necessarily includes a large collection of data in regard to the chemistry of asphalt and the technology of the industry, which is of interest only to civil engineers, asphalt experts and those who have made a special study of the subject. The general reader is recommended to omit Chapters III to VIII, XII, and most of XVI, or to confine his attention to the résumés of them which are presented at the end of each. The property holder and taxpayer will find the conclusions which will prove of most interest to him in Chapters I, II, and XIV, Summaries of III, XIII, XVI, and XVII to XXIV[1] relating to the construction of pavements and the causes of their deterioration. The relative merits of various asphalts for paving purposes are given in a compact form at the end of Chapter XIV. The importance of the action of water on asphalt in Chapter XXIII.[2] The résumé at the end of each Chapter will generally furnish the reader at a glance with an opportunity of determining whether the details in that Chapter appeal to his interest and intelligence.

THE AUTHOR.

NEW YORK, February 18, 1905.

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[1] Second Edition, Chapter XXV.

[2] Second Edition, Chapter XXIV.

PREFACE TO SECOND EDITION.

THE very flattering reception given to the first edition of this work, resulting in an exceedingly large sale within the last three years, has pointed to the very general interest in the subject treated of, by the persons for whom the book was especially intended. In consequence of the very considerable developments in the industry, it has seemed desirable, after the exhaustion of the second impression of the first edition, to revise the manuscript completely, and to bring it up to date. This has been done with the results given in the accompanying pages.

The writer is indebted to Mr. C. N. Forrest for a revision of the matter regarding the methods of analysis which are described, and for many other suggestions.

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THE MODERN ASPHALT PAVEMENT.

INTRODUCTION.

The object of this work is to demonstrate the nature of asphalt pavements and the causes of defects in them, to bring about improvement in the methods of their construction, and to show how this can be done.

During an extended experience in the asphalt paving industry, which has included the inspection of the construction of asphalt pavements on behalf of a large city and the technical supervision of the work of several prominent companies which contract to lay them, it has been forced upon the attention of the writer that engineers, and others who are interested in obtaining the best results, have not been made sufficiently acquainted with the technology of the industry and with the importance of some of the engineering details involved to enable them to differentiate, at the time that the pavement is being laid, or even on its completion, between good, bad, or medium work. Cities have, consequently, been obliged to rely on the statements and good faith of contractors, with the result that many asphalt pavements have eventually proved unsatisfactory, although when completed they were, to all outward appearance, of good quality—a condition which might have been readily avoided either by an intelligent supervision of the materials in use and the manner of handling them, or by a change in the form of construction.

It is proposed, therefore, to describe in the following pages the forms of construction which have been shown by experience to be the most satisfactory, the character of the materials entering into the composition of asphalt pavements, the most refined methods used in the industry at the present day and the reasons which have led to their adoption, in order that engineers and others who are responsible for the supervision and character of such work may be able to distinguish between that of good and that of inferior quality. To this will be added specifications for asphalt pavements to meet various environments and use, and something as to their maintenance and the causes of their deterioration.

The conclusions which are advanced are the results of twenty years' experience in the industry by the writer with pavements in over one hundred cities in the United States and in several in England, Scotland, and France, involving the construction of between twenty and thirty million yards of surface.

PART I.

THE FOUNDATION AND INTERMEDIATE COURSE.

CHAPTER I.

THE FOUNDATION OR BASE.

THE modern asphalt pavement in its perfected state is the evolution of thirty years of experiment and experience. It seems unnecessary here to give a history of the origin of this form of pavement on the Continent of Europe, or of the earliest experiments in the United States by De Smedt with artificial mixtures of sand and asphalt, as this information is readily available in numerous publications. It is sufficient to take the subject up at as late a date as 1894, when the first successful effort was made to place the industry on a rational basis as distinguished from the rule-of-thumb methods previously in vogue, and to follow it down to the most recent practice.

An asphalt pavement consists essentially of a foundation or support for the surface which is to carry the traffic, itself supported by the soil, and a surface consisting of a mineral aggregate cemented together with asphalt to protect the base from wear and disintegration, between which is commonly interposed either a course of broken stone coated with bitumen, known as binder, or some substitute for it, such as a cushion or separate course of the surface material, or a paint coat of bitumen dissolved in naphtha. These three elements of the pavement will be considered in turn.

The Subsoil Base.—As the foundation of a pavement, of any kind, is placed upon the soil and supported by the latter, it is a matter of vital importance that this latter support should be adequate, and it will only prove adequate if the subsoil is not subject to displacement from settlement or frost and is thoroughly drained.

With sandy soils which are well compacted and which, from their nature, are well drained and dry there is no difficulty in the preparation of a satisfactory subgrade. Trenches in such soils, if they occur, can be solidly refilled with the aid of water. If the subgrade is a true sand, as in the neighborhood of seabeaches, it may be necessary, in order to compact the surface, to spread a course of gravel between the sand and the base in order to be able to roll it properly.

With clay or heavy soils it is much more difficult to prepare a satisfactory subgrade, especially if this is likely to be subjected to the action of frost and if the original soil has been much disturbed by trenches, or if fills occur. If the subgrade consists of the original soil *in situ*, the only consideration necessary is its proper drainage, unless there are soft spots due to local causes, in which case they must be excavated and removed, with the substitution of firm for the softer material. The satisfactory back filling of trenches in a heavy soil is a difficult matter. The use of water is a disadvantage in such work. Heavy soils absorb and hold it tenaciously and thus prevent thorough compaction, final settlement only taking place after the completion of the pavement. Trenches in such a soil should be carefully and slowly tamped in thin layers.

The proper drainage of heavy clay soils is an essential feature in the construction of a satisfactory pavement, especially where these soils are apt to be thrown or cracked by frost in very cold climates, a condition which may be illustrated by that occurring in Manitoba, where cracks frequently open in the ground in winter, from four to six inches wide, and which would cause corresponding cracks in the asphalt surface were not some provision made against it. For this purpose a form of construction has been evolved which has proved quite successful by providing satisfactory drainage and not laying the hydraulic concrete foundation in direct contact with the subsoil. Upon the subsoil clean sand and gravel are spread and rolled to a depth of three inches, and upon this the hydraulic concrete foundation is laid. At the same time, at intervals of twenty-five feet, trenches are cut in the subsoil to a depth of six inches, and filled with coarse broken stone; these cross-drains being connected with similar trenches, containing coarse broken stone, under the curb, which are graded to catch-basins for the removal of water. In such a climate tile drains cannot be used successfully, the author is informed by the City Engineer of Winnipeg, because the ground is generally frozen when the surface-water first begins to drain away and this water filling the tile often freezes and bursts it. The provisions in use in Winnipeg seem to be an ideal way of treating heavy soils in cold climates and, although absolutely necessary in such a location, are extremely desirable where any soil of such a description is found. Further details in regard to this method will appear in the chapter on "Specifications."[1]

When a street is terraced and the roadway is lower than the adjacent property the greatest precaution should be taken to prevent the seepage from higher levels from working down between the soil and the foundation, or between the foundation and surface. For this purpose drainage should be provided below or along the curb, and at times in the subsoil itself.

The most serious subgrade to encounter as a support for a foundation is marshy or swampy land, fills made on the latter for the purpose of raising the grade, or even fills on ordinary soils where sufficient time has not elapsed to bring about final settlement and ultimate compaction. Where such conditions are unavoidable good practice calls for the use of a sufficiently strong hydraulic concrete foundation to bridge over irregular settlement and to distribute the load over weak points.

The cause of much of the deterioration in asphalt surfaces and in other pavements is due to a neglect of such precautions in regulating the subgrade or in providing a foundation of a character to bridge over defects in the latter.

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[1] Page 435.

It seems hardly necessary to state that any subsoil should be thoroughly compacted by a heavy roller of broad tread, and that any weak portions revealed by the use of such roller should be removed by treatment in an appropriate way.

The Foundation.—Foundations of most varied character have been used in the construction of pavements, including broken stone with or without a coating of more or less bitumen or coal-tar, macadam, old cobblestone pavement, an old surface of granite blocks or blocks turned and reset, old brick or asphalt-block surfaces, and hydraulic concretes of natural or Portland cement of varying thickness. Each of these forms has been more or less successful under different conditions, consideration being given to economy, to local environment, and to the traffic to be carried.

Bituminous Foundation.—The so-called bituminous foundation possesses no advantage save, in some cases, that of economy. It has been almost entirely abandoned as a support for asphalt surfaces. It is a relic of the days when hydraulic cement was a much more expensive article than at the present time. As generally constructed it consists of six or more inches of broken stone passing a two or two and one-half-inch ring and not containing any particles passing a one or one and one-half-inch ring. Stone of such uniform size contains a large volume of voids, forty per cent or over, and does not compact well. Were it the run of the crusher, the foundation would be far more satisfactory. Under the roller much of the stone is often lost in the subsoil before the required thickness is attained. The coating of bitumen applied to the surface of the foundation is of little or no advantage. Enough cannot be used to fill the voids, as if this is done the excess will be drawn up into the surface by a hot sun and destroy or soften the latter while the cost would also be prohibitive.

Additional disadvantages of such a foundation are that it possesses no rigidity or stability and consequently responds at once to any settlement or weakness of the subsoil; that it is porous and allows the free movement of water and gas, and that the binder and surface cannot be readily removed from it for renewal without its destruction.

Excellent asphalt pavements have been constructed with a bituminous foundation where the subsoil was firm and resistant and the travel light, as is the case in many residence streets, but surfaces equally good have been laid with broken stone alone. The cost of renewal of the surface of such pavements is, however, high, as has already been shown.

Macadam Foundation.—Old macadam has been used successfully in several instances as a foundation for asphalt pavement. It possesses many advantages over broken-stone. In macadam the voids in the stone are well filled with finer particles and it has received its ultimate compression under travel. It has not a coating of bitumen, so that the binder and surface coats are readily removed for renewal. It possesses the defect that the grade of the macadam can be altered but slightly without serious disturbance of its bond, and in replacing the pavement over trenches the stone becomes far less of a support than the original macadam. It, of course, presents the merit of economy. An excellent example of an asphalt pavement with a foundation of this class is to be seen on Broadway, above Fifty-ninth Street, in New York City, and on Michigan Avenue, to the south of Congress Street, in Chicago, Ill. The former street has been trenched to a large extent, and repairs have resulted very satisfactorily. The latter has a few cracks owing to the action of frost.

Other Old Pavement as Foundation.—Old cobblestone and asphalt-block pavements form an excellent foundation for asphalt pavements if the height of curb shown is sufficient and the amount of traffic permits. They should not be used if resetting is necessary except on very favorable soil and with the expectation of very moderate use.

Old granite-block pavements have been very extensively used for supporting asphalt surfaces, especially in New York City, and their value for this purpose and the defects which result therefrom are well illustrated there. Granite blocks laid in sand on the soil have been found very satisfactory on cross-town residence streets, but have been most unsatisfactory on streets like First Avenue, where the subsoil is soft, fills are frequent, and partly on land below high-water mark, in bringing the street originally to grade. These blocks could be seen to move under the steam-roller when the binder course was laid, and the asphalt surface is, in consequence, in constant need of repairs. The only foundation which would prove satisfactory under these conditions would be, considering the heavy travel on the street, the best form of Portland-cement concrete to a depth of at least eight inches.

Granite blocks on concrete make an excellent foundation for an asphalt surface, if not reset, but where the grade necessitates taking them up and replacing them on their broad sides the result is not satisfactory except on residence streets. When relaid they are not rigid, but have a tendency to rock under heavy travel. Such a foundation supports the asphalt surface on Broadway and several avenues in New York City, and has not been entirely successful. The turned blocks were opened to travel for some time to bed them thoroughly, and any loose ones reset. The binder and surface were then laid directly on the blocks. The vibration on these blocks, especially along the rail, is nevertheless large. A better form of construction would be to grout the blocks, after turning, with Portland cement, and keep traffic off of them until the grout is set. The lesson is that turned granite blocks should not be used as a foundation for asphalt pavements on streets of heavy travel, even when supported by Portland-cement concrete, and much less so on soil alone, as has recently been done on Fourth Avenue in New York City.

Construction of this description inevitably results in deterioration of the best asphalt surfaces, with the results that the defects are attributed to the asphalt and not to the foundation where they really originate. As a matter of fact no foundation is suitable for a street of heavy travel except one of Portland-cement concrete of sufficient depth and strength to carry the load imposed upon the surface with perfect rigidity, and it is equally true, as determined by years of careful observation, that ninety per cent of the defects in asphalt pavements in such cities as New York, where the surface mixture is of standard quality, are due to the insufficiency of the foundation.

Old brick pavements have served as a support for asphalt surfaces with entire satisfaction. They have received the full traffic of the street to be resurfaced and are therefore well compacted.

Such pavements, as their surfaces become too uneven for use, will, in the future, be largely renewed in this way.

Hydraulic-Concrete Foundation.—Hydraulic concrete, if properly proportioned, made with good cement and a well-graded aggregate, well mixed and put in place satisfactorily and in good weather, is the ideal foundation. Unfortunately these conditions are not always met. To discuss the possible variations and deficiencies in detail would be to write an elaborate treatise on the subject of concrete. It will suffice, however, to point out the chief merits and defects which appear most strongly in its use as a foundation for pavements.

The proportions of the different constituents, from which the contractor cannot depart, are sometimes injudiciously prescribed, and usually from motives of economy. In an eastern city a concrete foundation is specified which is to consist of one (1) part of Portland cement, four (4) parts of sand, five (5) parts of gravel, and five (5) parts of stone. While such a foundation may have sufficient strength to support a pavement carrying moderate travel, it is nevertheless porous and permits of the free movement of water and gas from below, both of which act on asphalt under such circumstances. The most favorable proportions which the writer has observed for a concrete for heavily travelled streets are those which were prescribed for Fifth Avenue, in New York City, in 1896. These were: one (1) part of Portland cement, three (3) parts of sand, two (2) or three (3) parts of gravel, and four (4) or five (5) parts of broken stone. If the stone were large the larger amount of gravel was used and the reverse. The gravel in the preceding concrete is of the greatest aid in filling the voids in the stone and in facilitating the compaction of the concrete when rammed. Stone with sand alone is very apt to bind, bridge, and resist compaction, while the voids are so large as to leave at times a portion of them unfilled with mortar.

The foundation thus constructed on Fifth Avenue has a depth of at least seven inches and is absolutely rigid. The asphalt surface placed on this is subject to no vibration and has shown no deterioration due to this cause in twelve years, while the same surface mixture supported only by the granite blocks on a soft soil in First Avenue was in far from good condition in a year.

This contrast between the two avenues with their different foundations is, therefore, most instructive and points to the fact that the primary consideration in an asphalt pavement is the foundation which supports it. Without a rigid one the best of materials and workmanship in the remainder of the pavement will go for naught.

Ordinary practice as regards the aggregate in a hydraulic concrete provides for broken stone all of which "will pass in any direction through a revolving circular screen having holes two and one-half (2½) inches in diameter and be retained by a screen having holes one (1) inch in diameter."[1] This may be good practice, but is certainly not the best.

The grading of the broken stone is an important consideration in adjusting the relations of the constituents in a well-proportioned concrete not only in a foundation for asphalt pavements, but in its use for every purpose. Fortunately this is rapidly becoming recognized. As has already been mentioned, the voids in broken stone passing a two-inch ring and not passing an inch and one-half or a one-inch ring are very large in volume, and it has been, and generally is, the practice to attempt to fill them with a mortar of one part of cement and three parts of sand, in the case of Portland, or two in the case of natural cement. This is not economical in more ways than one. It is much better to reduce the voids by using the broken stone as it comes from the crusher in well-assorted sizes and with smaller voids, the screenings passing a quarter- or three-eighth-inch screen only being removed, on account of its tendency to segregate and because it should actually be considered as sand, as will appear later, or to add gravel where it is available or where economy demands the separation of the inch stone for use in binder. The mortar then goes much farther, is not in such large masses, and the concrete is rammed and compacts with much greater ease. Under such circumstances, while the proportion of cement and sand should not be extended beyond one of the former to three of the latter, corresponding to the relation of the volume of the cement to the voids in the average concrete sand, the proportion of stone to the mortar may be largely extended beyond that which may be safely allowed for stone of uniform size and large voids.

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[1] Manhattan (New York) Specifications, 1901, paragraph 12.

Where good gravel is available, containing particles of sufficiently large size, a concrete made with this material without the use of crushed stone may be as equally satisfactory or even preferable to one constructed with stone alone or with a mixture of stone and gravel. A provision for such concrete is now contained in the specifications of some of our cities.

Where gravel occurs mixed with the requisite proportion of sand such a natural mineral aggregate can be employed in the manner in which Thames ballast is used in London, England, and with the most satisfactory results. The occurrence of such deposits in the United States is exceptional.

Another fortunate thing in recent practice is the recognition of the facts that a concrete the mortar in which is wet enough to almost quake under the tamper gives the most satisfactory results, since the slight early loss in strength due to the water excess is more than made up by the improved and thorough compaction attained. Dry concrete is no longer regarded as good practice.

In the early days of the asphalt-paving industry hydraulic concrete was usually mixed by hand labor on boards. To-day much of this work is very satisfactorily and much more cheaply done with the use of mixers driven by power. Of these there are a number of successful types now on the market, and, from the author's observation, they are strongly to be recommended where the extent of the work will justify their being employed.

Concrete Sand.—It is usually specified that sand in use in concrete shall be clean, coarse, sharp, and free from loam and dirt. The degree of coarseness is generally somewhat indefinitely expressed. Concrete sand as a rule contains but a small percentage of grains finer than will pass a fifty-mesh sieve. It may, however, contain to advantage a considerable portion of fine gravel. In this connection it may be remarked, however, that the permeability of a concrete is greater the coarser the sand, and that the presence of some fine grains is not undesirable. A small amount of loam or clay in sand is not injurious if it is not present in a lumpy condition. Many pit sands which have been rejected on account of the presence of loam make excellent concrete.

Crusher Screenings.—Sand has been defined as the detritus of rock, smaller than gravel and larger than silt. Under such a definition the screenings from the crushing of rock for the production of broken stone is sand and may be used as such in concrete. Its use for such purposes has attracted very considerable attention recently, and the results obtained with it have been most successful. The strength of the concrete in which sand is replaced by screenings is always equal to and in many cases in excess of that made with natural sand. It has been used, and pronounced a desirable material, in the concrete of the Buffalo breakwater,[1] in the Manchester and Liverpool (England) water-works,[2] in the Jerome Park Reservoir in New York City, in masonry construction on the C. M. & St. P. R. R., and in the concrete on the Water-power Sections Nos. 1, 2, and 3 of the Chicago Drainage Canal. It has been tested by many engineers in the laboratory and found to produce concrete exceeding or equalling in strength that made with sand. An excellent résumé of the availability of this material will be found in "The Cement Age," Vol. 1, No. 3, page 5, August 1904, and in a publication of the Producers' Supply Company, entitled "Crushed Stone and its Uses," pages 100, 103, and 107, Chicago, 1904.

It has been successfully used in the concrete foundation for asphalt pavements in several cities, and its use for this and other purposes is rapidly increasing. The author made the following statement in connection with the use of crusher screenings as a witness before the Aqueduct Commissioners of the City of New York when this was objected to by the Merchants' Association of the city:

"The advantages are that the particles in the crusher screenings are better graded in size, and in consequence those screenings have a smaller volume of voids or unfilled cavities in them. As a result a definite volume of Portland cement will go farther towards filling those voids than with sand, where the particles are more uniform in size and the volume of the voids large. . . ."

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[1] Eng. News, Sept. 11, 1902.

[2] Hill, Institution of Civil Engineers, London, 1896; Deacon, *ibid.*

There can be no question that crusher screenings are preferable to many natural sands when the rock in which they originate is of desirable quality.

Character of the Hydraulic Cement in Use.—The character of the hydraulic cement in use in concrete foundations is as important as any constituent of the pavement. If it is defective in any way, the result will be shown in the surface. In one case one of the most prominent surfaces in the country became cracked across the street at wide intervals two years after it was laid, and in three years the surface was noticeably raised at these points. On opening the pavement the cracks in the surface were found to be due to cracks in the concrete formed during the first two years, and the elevation of the surface, which occurred later, to the subsequent expansion of the cement, which in this way pushed one portion of the foundation upward and over the other, although the cement was a Portland and one which responded satisfactorily to all short-time tests for constancy of volume. A similar experience was met with for several years with the natural cements of western New York, and it was generally necessary, where one brand was used, to remove the surface and cut out the expanded portion after a few years in order to bring the surface of the pavement to grade.

In the middle West serious troubles due to the character of the natural cement in use were often met with before Portland cement became available. The natural cements of that part of the country are not always reliable or uniform and are especially unsuited for use in cold weather, as they fail to set when the temperature approaches freezing. The writer has frequently seen hydraulic foundations which have acquired no bond, either from their inferior quality alone or because of use in cold weather. Such a foundation is open and porous and allows water to reach and disintegrate the asphalt surface. It frequently cracks after a firm set has taken place, and these cracks are eventually repeated in the asphalt surface, as can be seen in the accompanying illustration, Fig. 1. The evident conclusion is that the use of natural cement in concrete for the foundation of asphalt pavements should be

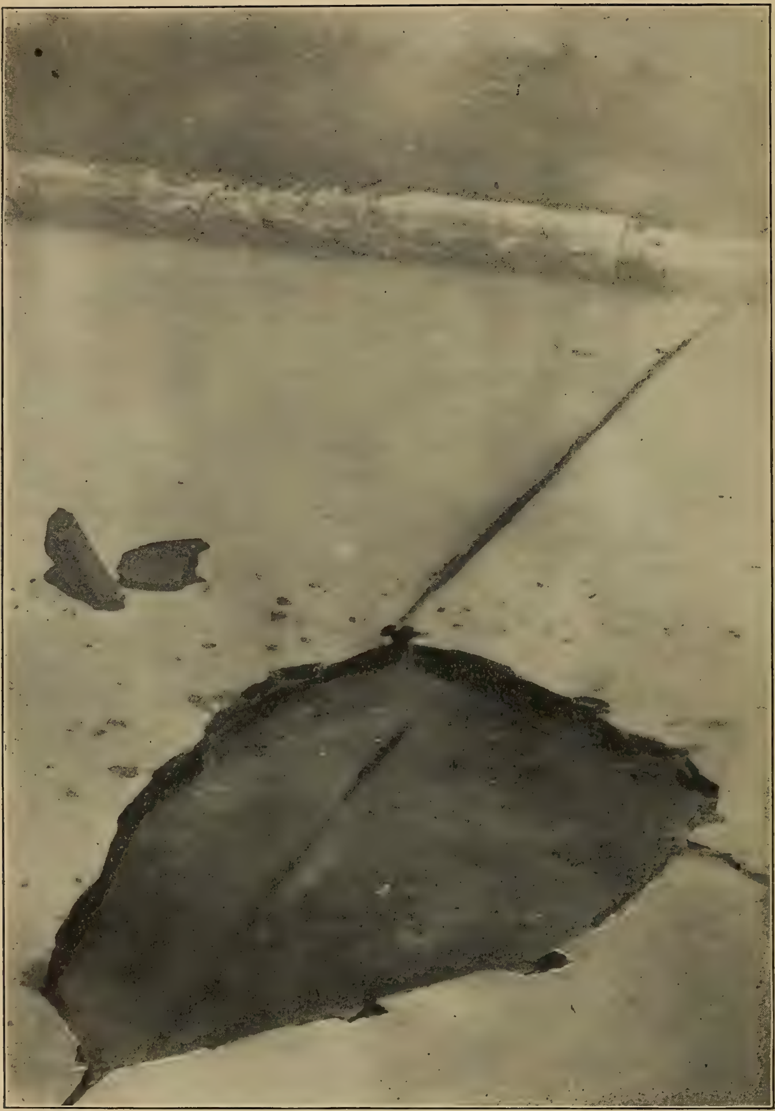

Fig. 1.

abandoned, although it would not be justifiable to suppose that none made from this cement or even the majority of it is poor. That under the first asphalt pavement of any area, on Pennsylvania Avenue, Washington, D. C., was constructed with natural cement from the Potomac Valley, and during thirty years gave entire satisfaction. Foundations containing the Rosendale cements have proved equally good, but all the natural cements of this description attain their strength so slowly that an unfortunately long period must elapse before they will safely sustain a heavy roller suitable for compressing the binder and surface, and in this way the completion of the pavement is delayed. It is therefore much better to avoid using natural cements, and the substitution of Portland cement has become the very general practice.

All hydraulic cement in use in the construction of asphalt pavements should be tested before it is allowed to go into the work, and should meet the requirements which the local engineer believes to be reasonable. The Committee on Uniform Tests of Cement of the American Society of Civil Engineers has recommended methods which should bring about greater uniformity in testing cements, and their use is suggested.[1]

A similar committee of the American Society for Testing Materials has recommended reasonable specifications for cement which can be adopted if they meet with the approval of the engineer.[2]

Lateral Support.—Closely related in importance to the character of the foundation of the pavement is that of the lateral support which the surface receives.

It is quite as well proved by experience that more defects in asphalt surfaces are due, proportionally to the area involved, to the lack of this than to weak foundation and, often, to all other causes.

The lateral support should be as rigid as in the case of the foundation, and unfortunately it is not always so about manholes, water- and gas-boxes, at headers where the surface ends, and especially against rails. Vibration about manholes, boxes, etc., can be avoided by providing heavy castings with a broad base and setting them upon a proper foundation in Portland cement a sufficiently long period before laying the surface to prevent them from being loosened by a blow from the roller. Headers should be sufficiently heavy to hold the surface up and resist the impact of traffic.

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[1] Proceedings Am. Soc. C. E., 1903, 29, No. 1.

[2] Report of Committee C on Standard Specifications for Cement. Presented at Annual Meeting, 1904, June 17.

The construction of a street car-track the rails and sleepers of which shall be sufficiently free from vibration to form a support for an immediately adjacent asphalt surface is a most difficult matter and one that is rarely successfully carried out, especially when trolley-cars of the size and weight of those in use to-day are to be considered.

Experience has shown that construction involving the use of a very heavy girder-rail placed upon ties, which, together with the rail, are embedded in concrete from the base of the former to the height of the adjoining foundation of the pavement, is the best. Such construction will be, however, of little value if traffic is allowed over the rail before the concrete has had time to set thoroughly. In cases where the soil is very heavy and the drainage is bad crushed stone used as ballast may often prove more satisfactory than hydraulic concrete, as affording better drainage. Where mud forms, owing to poor drainage, and works into cracks between the asphalt surface and the concrete the result is very disastrous.

Another form of rail construction which has met with considerable approval is the placing of the rail upon a hydraulic concrete beam extending its entire length. It is possible that this may be desirable where carefully carried out, but, in the author's experience, where a girder-rail of sufficiently heavy type is to be used no advantage is derived commensurate with the expense, and the possibility of vibration is not lessened.

If vibration still takes place in a rail, even with the best form of construction, and this is rarely absent with heavy trolley-cars, a triple row of the best paving-blocks, or bricks, laid with broken joints parallel to the rail should be placed against it, bedded in cement, and well grouted, depressing the base sufficiently for this purpose. *Header and stretcher construction is most faulty.* The asphalt toothing is then a point of weakness.

Vibration of the rail will eventually destroy an immediately adjoining surface not only by breaking the bond between the particles of the surface, but by admitting water and mud after the first fracture has taken place.

All the defects which are due to weakness in the foundation and to the lack of lateral support involve not only an expense to the contractor during the guarantee period which he must consider in his bids after a study of the form of construction specified by the city, but will also prove an additional cost to the city when it takes over the maintenance of the street. Economy in the cost of the pavement in this direction may not prove true economy in the end.

While it is not, of course, necessary that a needlessly expensive foundation should be provided for an asphalt pavement, it will eventually prove cheaper if a good margin of safety in this direction is allowed. An asphalt surface is no stronger than its weakest part.

SUMMARY.

It appears that better concrete can be made of graded broken stone than of stone of uniform size, that the addition of gravel is an improvement, that a concrete consisting of gravel alone as a substitute for broken stone will often prove satisfactory, that crusher screenings are an excellent substitute for natural sand, that Portland cement is infinitely preferable to natural cement, that the greatest care should be used that the pavement should have a proper lateral as well as vertical support, and that the greatest attention should be paid to the rigidity of railroad-track construction.

It seems, therefore, that while an asphalt pavement of the best quality can be constructed only when all its elements—foundation, binder or its substitute, and surface—are of the highest degree of perfection, refinement in the character of the binder and surface is thrown away if the subsoil is not satisfactorily drained and if the foundation of the pavement is not sufficiently strong to carry the traffic to which the surface is subjected with entire rigidity and is not sufficiently impervious to protect the surface from the action of water and illuminating-gas.

In addition a well-constructed foundation is a matter of economy, as it should last for all time and will only require resurfacing at intervals, whereas an inferior one must eventually be renewed by one properly constructed.

CHAPTER II.

THE INTERMEDIATE COURSE.

In the early days of the asphalt-paving industry a thicker wearing surface was in use than to-day. That of 1876 on Pennsylvania Avenue in Washington, D. C., and most of those laid in the following fifteen years were two and one-half inches thick. These surfaces were laid in two courses, and are thus described in an old specification of a Washington contractor in 1878:[1]

"The asphalt (surface mixture), having been prepared in the manner thus indicated, is laid on the foundation in two coats.

"The first coat of one-half inch thickness, called protecting coat, might be laid richer in asphaltic cement, and may be consolidated simply by rolling with iron or stone rollers weighing about 1000 pounds or half a ton.

"On this first asphalt coat is then carefully spread with iron rakes the final finishing coat," etc., etc.

It is evident from this that the one-half-inch coat of surface mixture was laid for no other purpose, at this time, than to protect the rather friable hydraulic concrete of natural cement from being broken up by hauling the final surface mixture over it. It will be noted that it is suggested to lay the first coat of material richer in asphalt cement.

In 1884 the specifications which the city itself adopted were evidently based on those of 1878, but the wording was somewhat changed, "pavement mixture" replacing "asphalt" in the first paragraph quoted, and "cushion coat" for "protective coat," with some other minor alterations, in the second, the thickness of the latter remaining one-half inch "after being consolidated by a roller," while it is to contain, specifically, "from two to four per cent more asphaltic cement" than the "surface coat."

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[1] Rept. of Com. D. C., 1878, 292.

In the interval mentioned the term "protective coat" which casts some reflection on the character of the foundation has, therefore, been changed to "cushion coat." The greater richness of the cushion has been retained.

In the specifications for 1886–87 no mention is made of a protective or cushion coat. It is provided that the surface mixture will be "carefully spread, in such a manner as to give a uniform and regular surface and to such depth as, after having received its ultimate compression of 40 per cent, to have a thickness of 2½ inches."

The cushion coat was temporarily abandoned in that year. The reason for this is instructive, as showing the defects of this method of construction. Surfaces laid with a thickness of two and one-half inches the lower part of which consisted of a protective or cushion coat richer in bitumen were liable to serious displacement under travel, with the result that the surface became very wavy and uncomfortable to drive over, an experience met with in other cities as well, and which subjected such asphalt pavements to unfavorable comment. The excessive thickness and the richer cushion coat permitted not only of this displacement of the surface, but also allowed its movement on the foundation under the impact of wheels of vehicles, when once the waves were formed, especially where travel, as in streets with car-tracks, was confined in one direction.

The change in the specifications in 1886–87 was intended to avoid this by doing away with the cushion and compacting the entire surface at once. It was an improvement, but for some reason the provision for a cushion coat one or two per cent richer in asphalt appeared again in the specifications for 1887–88. No asphalt pavements were laid in Washington during this fiscal year, as the city was compelled, by provisions in the act making appropriations for the purpose, not to go beyond a limit in price for such pavement for which the contractors refused to lay asphalt. A return was, therefore, made to coal-tar with disastrous results, the only gain being that when asphalt surfaces were again laid in 1888 the excessive thickness of the surface was reduced and a course of broken stone coated with coal-tar or asphalt was introduced which had been an element of the so-called distillate pavements of the intermediate period. This gain was a distinct one for the asphalt-paving industry all over the country, as it did away with the displacement of the thicker surface under traffic. No general return to the original method of construction without this course has been made since that time except in two or three cities, and there with less unsatisfactory results than formerly owing to the more careful grading of the mineral aggregate in modern mixtures and their greater stability.

The Binder Course.—The binder course, as has been said, is an inheritance from the days of coal-tar pavements with broken stone foundations, and its use in combination with an asphalt surface was the result of an attempt to improve upon the unsatisfactory distillate pavement, so called, laid in Washington in 1887, by substituting an asphalt for a coal-tar surface, leaving the foundation and binder unchanged. Eventually a hydraulic concrete foundation was substituted for the broken stone and the result was the modern form of construction.

The binder course was evidently the result of an attempt to close the large openings in the broken-stone foundation by a course of finer stone in order to prevent the loss of the more expensive surface mixture by its compression into the voids of the former and with no idea of preventing displacement in the surface. That it accomplished this was only detected when it was noticed that its use as a matter of economy in reducing the thickness of the asphalt surface from two and one-half to one and one-half inches produced this desired result. From Washington in 1888-89 the binder course rapidly spread over the country and proved successful. In its original form it consisted of ''clean broken stone, thoroughly screened, not exceeding one and one-fourth (1¼) inches in the largest dimension and No. 4 coal-tar paving cement."

The coal-tar was soon replaced by an asphaltic cement and the broken stone in some cities by a smaller stone passing an inch ring with the grit and finer material removed.

From a binder constructed in this way there has been little departure for many years, although recently the possibility of some improvement in this course has become very evident. The original course was one and one-half inches thick when compacted, a depth quite necessary with one and one-fourth inch stone. With finer stone and for economy inch binder has frequently been specified, but there can be little or no bond to such a thickness and its use in this way is plainly poor practice.

It is generally specified that the binder stone shall pass a one and one-fourth- or one-inch screen and contain not more than a certain percentage of fine material. This is a great mistake, as in the case of hydraulic concrete, since the more fine material the stone contains, up to the point where the voids in the large particles are filled, the more compact and desirable the binder is. At the same time a binder with much fine material requires a larger amount of asphalt cement and is consequently more expensive. If the contractor is willing to assume this extra expense no objection can be raised to such a practice.

The amount of asphalt cement necessary to coat satisfactorily a binder of clean stone free from grit and dust will vary with the character of the stone and the nature of the asphalt cement. With Hudson River limestone or trap three per cent of bitumen is sufficient, and this is represented by that amount of an asphalt cement composed of pure bitumen or four per cent of one made with Trinidad asphalt. With the softer limestones of the middle West, a higher percentage is occasionally necessary. The exact amount can only be determined by experiment. It should not be sufficient to run off of the hot stone or too little to give a bright glossy coat. An excess may result disastrously, as it will collect inevitably in pools or spots where the binder has been taken from the bottom of the truck in which it has been hauled to the street, and the excess collecting at these points may be drawn up by a hot summer sun and soften the surface of the pavement or even appear in mass thereon, as has happened in one or two instances in a western city.

On the other hand, a slight and well distributed excess may prove of decided benefit on streets having little or no traffic, where the surface would be apt to crack ordinarily. It has been found that in such a case the surface is slowly enriched by the excess, and is thus preserved.

An example of this enrichment was observed in an Alcatraz surface laid on a very rich binder in a western city in 1889. A specimen of the surface was analyzed several years after it was laid, after separating it into top and bottom sections. The results were as follows:

Section.	Bitumen.	Passing Mesh.							
		200	100	80	50	40	30	20	10
Top......	9.8	12.2	10	31	32	3	1	1	0
Duplicate.	9.8	11.2	10	31	33	3	1	1	0
Bottom. .	10.3	11.7	10	32	32	2	1	1	0
Duplicate.	10.7	11.3	10	33	31	2	1	1	0

The bottom of the pavement carries, on an average, seven-tenths per cent more bitumen than the top, and that this is no accident in mixing appears from the uniformity of the sand grading in all the samples of the different sections.

The consistency of the asphalt cement in use in binder should be softer than that in the surface for several reasons. The ordinary binder is a very open material which permits the volatilization of oil from the asphalt cement by the heat of the stone, especially if the stone is accidentally too hot and the haul to the work a long one, with the result that the cement becomes much hardened and more brittle. In the second place the tendency to the rupture of the bond between the fragments of binder stone is much less with an asphalt cement of soft than of hard consistency.

Good practice leads to the use of a cement for binder which is twenty or more points softer, by the penetration machine, than that in the surface.

The actual temperature of the binder as it is laid on the street should be no greater than is necessary to make it possible to rake it out. It may be much colder than an asphalt surface mixture.

Recent experience has shown that there are defects in such a binder which are due to the fact that the voids are unfilled and the course lacks stability and solidity. Such defects have been manifested in two ways for many years. If binder is not laid with great attention to the character of the asphalt cement which covers the stone and binds it together it soon loses its bond under heavy traffic and, the stone itself having but little supporting power, the asphalt surface goes to pieces. If, on the other hand, the binder stone itself is not a strong one it is frequently crushed by the weight of heavy traffic and the surface, losing its support, either goes to pieces or the crushed binder is forced into it irregularly, thus causing a decided displacement which eventually results in disintegration.

In individual cases the surface has been observed to have been driven by traffic into the voids in the binder without displacement, with the result that the thickness of the pavement has been much reduced, although in this condition it is a much more rigid mass than as it was first constructed.

The binder previously described has consisted of stone practically or largely of one size, three-quarters to one and one-half inches in the largest diameter, as appears from the following analyses:

Test number....	69978		70804		70854		71102		74893	
Bitumen........	5.4%		4.4%		3.8%		3.6%		3.5%	
Filler...........	5.8	26.8	4.1	16.0	2.2	9.7	2.4	5.4	1.5	4.5
Sand.	21.0		12.5		7.5		3.0		3.0	
Stone:										
Passing ¼″ sieve	5.8	67.8	8.7	79.0	18.0	86.5	13.5	91.0	49.5	92.0
" ½″ "	13.6		46.8		52.0		51.5		10.0	
" 1″ "	41.4		23.5		16.5		26.0		32.5	
Retained 1″ "	7.0		0.0		0.0		0.0		0.0	
	100.0		100.0		100.0		100.0		100.0	

It will be seen from the preceding results that the percentage of bitumen which binder will carry depends largely upon the amount of fine material which it contains, binder No. 69978 with 26.8 per cent of fine material holding 5.4 per cent of bitumen, while those made from cleaner stone where the fine material does not exceed 5 per cent, carry less than 4 per cent of bitumen. If the stone in use is not screened, but contains all the finer particles coming from the crusher, the binder will be more satisfactory.

Asphaltic Concrete Binder.—The weakness of the ordinary open-binder course, where subjected to heavy traffic, can be avoided by filling the voids in the material with fine stone or grit and the remaining voids, after this addition, with sand or a mineral aggregate corresponding in grading to that of a standard surface mixture.

Such a binder has given most excellent results in supporting an asphalt surface on an ordinary foundation, such as turned or reset blocks or alongside of poorly constructed street-railway tracks, such as those on Broadway in New York City, being in itself perfectly rigid.

A good example of this form of construction on a hydraulic concrete foundation may be seen on Court Street in Boston, from Washington Street to the old Court House, and on Kilby Street in the same city, between State and Central Streets. A photograph of a sawn section of such pavement is shown in Fig. 16.

The manner in which a binder of this type, which is generally known in the industry as close or compact binder, is turned out at the plant is much the same as that used in preparing an asphaltic concrete to be used as a wearing surface, with the exception that it contains no filler, and will be described in a later chapter. It will be of interest, however, to give some examples of the proportions in which the various components have been employed in actual practice during the year 1907, together with the results of analyses of the finished binder. (See Table on page 26.)

Close binder of the Boston type is probably more desirable than that produced in New York, owing to the larger percentage of three-quarter inch stone which it contains and its consequent greater stability, but as the stone at that point is not separated into two sizes after heating, but drawn from one bin, there is probably a greater amount of segregation in the mixture than in that turned out at New York, where stone of each size is separated and weighed out in definite proportions. Nevertheless, a very satisfactory asphaltic concrete for the binder course has been turned out in Boston in that way, with the exception that where

	New York.		Boston.
	Plant 1.	Plant 2.	
Coarse stone..........	480 lbs.=54.6%	480 lbs.=53.3%	} 885 lbs.=73.4%
Fine stone...........	200 " 22.7	202 " 22.4	
Sand................	150 " 17.0	150 " 16.7	250 " 20.8
Trinidad asphalt cement		68 " 7.6	70 " 5.8
Bermudez " "	50 " 5.7		
	880 lbs. 100.0	900 lbs. 100.0	1205 lbs. 100.0

ANALYSES:

Bitumen soluble in CS_2.	5.6%	5.2%	4.8%
Passing 200 mesh screen	4.4	6.4	4.2
" 10 " "	29.2	29.0	26.4
" $\frac{1}{8}$ " "	1.8	2.0	.8
" $\frac{1}{4}$ inch "	10.0	7.0	4.4
" $\frac{1}{2}$ " "	23.2	25.8	24.4
" $\frac{3}{4}$ " "	13.6	17.8	32.2
" 1 " "	7.4	6.8	2.8
Retained 1 " "	4.8	0.0	0.0
	100.0	100.0	100.0

there is segregation of the finer material, it sometimes happens that there will be a displacement of the surface of the finished pavement at that point.

On this account, there are one or two points which experience has shown must be guarded against. The fine material should not be at all in excess of an amount sufficient to fill the voids in the stone, since, if this is the case, too smooth a surface will be obtained, with resulting displacement of the wearing surface. An excess of bitumen must also be avoided for the same reason.

In the construction of an asphalt pavement with an asphaltic concrete binder course, the surface should be applied to the binder before it has become entirely cold, in order to obtain a satisfactory bond. It is not possible to do satisfactory work where a large area of close binder is laid on one day and covered with surface on the next. There should be an alternation of the binder and surface courses, for example, no more binder should be laid in the beginning of a day than can be covered with surface during the remainder of the available working hours.

Where old surface mixture is available and facilities are at hand for softening this by means of heat or by grinding it in a disintegrator, such material can be used quite as satisfactorily for filling the voids in an ordinary binder as new sand and filler, thus reducing very much the cost of a concrete binder course. The percentage of asphalt and its consistency in such a case will, of course, be regulated by the amount already present in the old material.

The form of construction involving the use of a compact binder naturally increases the cost of the pavement to a certain extent, but the advantages gained more than make up for this, since its life will be extended to a degree more than sufficient to bring the cost per year below that of one in which the old open form of binder is used, especially on streets of heavy travel. In the author's opinion it is the most important advance that has been made in the asphalt paving industry since the evolution of the rationally graded surface mixture in 1896. Its use is specified in Kansas City and Omaha, as can be seen in the very excellent specifications of the former city, which are reprinted in the appendix.

Paint-coat.—Some of the defects in a pavement due to an open binder can, perhaps, also be removed by abandoning it entirely and substituting therefor a so-called paint course which consists of an asphalt cement of suitable consistency dissolved in benzine, 62° B., and then applied with a brush or squeegee to the surface of the hydraulic foundation, which should be made, if this coat is used, of Portland cement, or else floated with a mortar of this cement, and should have a comparatively smooth surface. The coating should be bright and glossy, but not sticky, and it must be carefully protected from becoming dirty. It cannot be applied successfully to a concrete that is in the slightest degree damp, as the adhesion is then imperfect. If well done, and this requires some skill and experience, the surface mixture applied directly to this coat will be cemented firmly to it and any displacement in the surface on the foundation will be prevented if the mixture itself is stable.

The first use of such a coat as a substitute for binder was made in a town in Ohio in 1896, where an asphalt surface was laid on an old brick pavement, the grade of which did not permit of the use of a binder course. The adhesion of the surface to the brick was afterwards found, on making cuts for water and gas connections, to be so strong that the upper portions of the brick were torn away with the asphalt surface. On one or two streets in New York on which very heavy coal trucks are constantly passing, and where the binder course was frequently crushed, a similar construction on a Portland-cement base was successful.

Specifications for the use of paint coat are as follows: "Upon the surface of the foundation of the Portland cement concrete, a paint course shall be applied to bind or tie the surface course to the foundation. For this purpose, the surface of the cement concrete shall, in its preparation, be well rammed, so that mortar shall come to the top, and it shall be made so smooth that no depression shall exist of a depth of more than three-eighths ($\frac{3}{8}$) of an inch. The paint for use shall consist of 62° B. naphtha and any satisfactory asphalt cement free from mineral matter, and of a consistency such as will allow the penetration, at 77 degrees Fahrenheit, of a No. 2 needle weighted with 100 grams, of not more than three (3) millimeters, and not less than two (2). The asphalt cement shall be dissolved while soft and warm, in the naphtha in such proportions that the resulting paint shall give a glossy surface after evaporation of the latter, but at the same time can be applied so as to form as thin a coating as possible. The proportions will vary, depending upon the temperature at which the paint is made, but shall be about 240 pounds of asphalt cement to 50 gallons, or one barrel, of naphtha.

"The concrete foundation shall be carefully swept and thoroughly cleaned of all foreign matter. The paint coat shall only be applied to it when the latter is absolutely dry and free from the slightest dampness, as otherwise it will not adhere. It should be used in such quantity that fifty (50) gallons will cover from 350 to 400 square yards of the concrete surface.

"No more of the surface of the foundation shall be painted than can be covered with asphalt surface mixture within a few hours after the application. Under no circumstances shall the paint coat be allowed to become in any way dirty, nor shall the surface mixture be permitted to be applied to such a coat more than five hours after the painting has been done.

"Owing to the inflammability of naphtha, the paint shall be prepared at a distance from all fire or flame and shall be applied to the surface of the concrete with the same precautions."

SUMMARY.

In the preceding chapter it appears that the use of a so-called cushion coat—that is to say, the application of the surface mixture to the foundation in two courses instead of one—is usually unsatisfactory and has generally been abandoned. The ordinary open-binder course has been shown to be defective, owing to its lack of stability, on heavy-traffic streets and the substitution for it of a compact binder has been recommended, or, where economy is desired, the use of a paint-coat to tie the surface mixture to the foundation.

An open binder course of this description will no doubt continue to be very generally an element in the construction of the majority of asphalt pavements which are subjected to only moderate traffic.

PART II.

THE MATERIALS CONSTITUTING THE ASPHALT SURFACE MIXTURE.

CHAPTER III.

THE MINERAL AGGREGATE.

The asphalt surface, which directly carries the traffic and which is intended to withstand the wear and tear of the same and the action of the elements, is composed of a mineral aggregate and an asphalt cement, that is to say, it is an asphalt mortar or concrete.

The mineral aggregate consists of sand, in exceptional cases also of stone, and a fine mineral dust or filler.

The asphalt cement consists of a native hard asphalt, or some hard residue from an asphaltic oil or maltha, softened to the proper consistency by some heavy petroleum oil, generally the residual product of the distillation of petroleum.

Before considering surface mixture as a whole the constituents which enter into its composition must be examined individually and the variations which are met with in them noted.

The Mineral Aggregate.—*Sand* —Sand is the detritus of rock, consisting of particles smaller than gravel and larger than silt, and produced either by natural causes such as weathering and water action or by the hand of man in crushing rocks mechanically.

Natural sand is the detritus, generally, of crystalline rocks and commonly water borne and water worn, in which quartz usually predominates, although calcareous sands, and those composed entirely of feldspar or largely of other silicates, are known.

Artificial sand consists of the particles, produced in the process of crushing rocks, which are of corresponding size to those which make up natural sands.

Sand is the principal constituent of asphalt pavements, and as such demands careful attention and study. Mr. A. W. Dow has remarked in a paper before the Society of Municipal Improvements in 1898:

"As sand is 90 per cent of the pavement, why should it not be the most important ingredient to consider; and when a pavement is at fault, why should it not be more responsible than the asphalt which now bears the brunt of all failures?"

As a matter of fact it is now pretty well known that, even if all the other constituents of an asphalt surface mixture are of the best, the wearing surface will not prove a success unless the sand is suitable for the purpose.

In the early days of the asphalt-paving industry but little attention was given to the subject and the sand in use was whatever happened to be the most available at the particular locality where work was being done. Later, opinions varied as to whether a coarse or a fine sand was more desirable, and there was a vibration from one to the other, together with equally wide variations in the consistency of the asphalt cement. In 1890 we find an expert of that day stating that he is "pretty well convinced that sand and matter that passes the 60 mesh ought not to enter the mixture"; and again in 1892, having examined "ten old pavements that have withstood wear," saying: "taking these results [of his analyses] on the face of it, it is observed that in general the sand used was on the fine side." No definite conclusions were drawn at that time as to what a desirable sand was.

To-day we are better informed as to the best sand for a good surface mixture, but unfortunately we know too little in regard to the cause of the varying character of the particles composing the quartz sand which is used. We have not been able to tell why a certain Missouri River sand produces such a mushy mixture and is so unsatisfactory that its use has had to be abandoned, or why a Platte River sand is possessed of peculiarities seen in that from no other river.

Difference in the shape of the grain and in the character of its surface are the probable causes, and these characteristics of a sand are, therefore, probably next in importance to the composition and size of the grains in determining its suitability for paving purposes.

Sorby,[1] who has studied the subject of sands carefully, has classified them as follows:

"1. Normal, angular, fresh-formed sand, such as has been derived almost directly from the breaking up of granite or schistose rocks.

"2. Well-worn sand in rounded grains, the original angles being completely lost and the surfaces looking like fine-ground glass.

"3. Sand mechanically broken into sharp angular chips, showing a glassy fracture.

"4. Sand having the grains chemically corroded, so as to produce a peculiar texture of the surface, differing from that of worn grains or crystals.

"5. Sand in which the grains have perfectly crystalline outline, in some cases undoubtedly due to the deposition of quartz upon rounded or angular nuclei of ordinary non-crystalline sand."

In the paving industry all these sands have been met with, but grains of several kinds not mentioned by Sorby are frequently found. From an examination of several hundred sands from different localities the writer has been able to classify them, according to their source, by peculiarities of composition, by the shape, and by the surface of the grains, as follows:

Classification of Sand.

Source:
  Commercially.
  1. Beach sand.
    Seashore.
    Lakeshore.

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[1] Q. J. Geol. Soc., 1880, 36, 58.

2. River sand.
3. Bank sand.
4. Sand derived from soft sandstone.
5. Artificial sand.

Or with especial reference to their physical origin.

1. Beach sand.
    - Marine—tidal action and sorting.
    - Lakeshore—storm action and sorting.
2. Alluvial sand.
    - Subaqueous, recent.
        - Stream.
        - Lake.
    - Bank or pit deposits.
    - Glacial, stream, lake, etc.
3. Æolian sand.
    - Dune.
    - Loess.
    - Volcanic.
4. From sandstone.
5. Crushed stone.

Composition:

- Silica.
    - Quartz.
        - Hard clear.
        - Soft cloudy.
        - Ferruginous.
- Silicates.
    - Shales and schists.
    - Feldspar.
    - Hornblende, Pyroxenes.
- Calcareous.
    - Limestone.
    - Carbonates.
    - Shell.
    - Coral.

- Mixed composition.
    - Various kinds of quartz.
    - Quartz and silicates.
    - Quartz and carbonates.
    - Quartz and shell.

Shape:

- Irregular.
    - Sharp angles.
    - Rounded angles.
- Oval.
    - Worn by water action.
- Round.
    - River.
    - Glacial.
    - Rock.
- Crystalline.

Surface:

- Sharp, original or fractured surface, not at all or little worn.
- Slightly worn on edges.
- Smooth and polished "soft sand."
- Smooth and with surface like ground glass.
- Covered with cementing material.
- Acted upon chemically.
- Porous, coral sand, limestone sand, shells.

Size of grains:

- Uniform.
- Particles distributed in size, well graded.
- Quicksand.

These different classes of sand may be described with special reference to their use in the asphalt industry.

Beach Sands.—*Seashore.*—These are little used because as a rule they are so sorted by currents of more or less uniform hydraulic value that they are too much of one size. For example, a sand found on Rockaway Beach, Long Island, is made up of grains passing the following sieves:

Passing 200-mesh sieve	0%
“ 100- “ “	7
“ 80- “ “	32
“ 50- “ “	57
“ 40- “ “	2
“ 30- “ “	1
“ 20- “ “	1
“ 10- “ “	0
	100

It appears that 89 per cent of all the particles in the sand are of 50- and 80-mesh size. The tidal currents are such that particles of smaller size are washed away while the larger ones have been left behind in the movement of the beach sand to its present location.

As far as character of the grain is concerned beach sands often, and in fact in most cases, could not be improved upon. Fig. 2, No. 1.

The most remarkable seabeach sands in the United States are found on the eastern coast of Florida. They consist, on the beaches of the northern part of the State, of pure white quartz grains which have a fresh and angular fracture. Further south, as at Lake Worth Inlet, they are made up of quartz and shell fragments of about the same size. The grains are much coarser owing to local conditions. Fig. 2, No. 2.

An explanation of the presence of quartz sand at a point so far distant from any rock formations which contain this material can only be arrived at by assuming that this mass of sand has been transported down the coast by tidal action and ocean currents.

No. 30516—Lake Worth Inlet; bar sand; about 6 miles from Palm Beach, Florida.
“ 30534—St. Augustine; north beach; from dunes 10 to 15 feet high.
“ 30535—“ “ “ “ along high-water line; river side.
“ 30536—“ “ “ “ “ “ “ ocean side.
“ 30547—St. John's Bluff.
“ 30546—Mayport, Duval County; from 1 mile south of Mayport, ¼ mile from ocean.
“ 30548—Mayport, Duval County; from sand-dunes 10 feet high.

Test number.	30516	30534	30535	30536	30547	30546	30548
Passing 200-mesh	0%	1%	1%	1%	1%	2%	1%
" 100- "	1	45	31	32	18	6	39
" 80- "	1	41	50	50	39	20	50
" 50- "	16	12	17	16	26	39	9
" 40- "	40	1	1	1	10	19	1
" 30- "	22	0	0	0	2	8	0
" 20- "	15	0	0	0	2	4	0
" 10- "	5	0	0	0	2	2	0
	100	100	100	100	100	100	100
Retained 10- "	.4%	——	——	——	1.1%	2.0%	——
Soluble in HCl. . .	45.9%	1.5%	2.7%	——	.8%	1.2%	——

The above sands are all pure quartz with the exception of sample No. 30516 from Lake Worth Inlet, which contains 45.9 per cent shell detritus.

The beach sands of Cuba, to the west of Havana, are composed entirely of small shell fragments, while those on the south coast to the east of Santiago are either coral or, in Daiquiri Bay, largely of hard silicates, the particles being transparent and of the rich color of hornblende.

Seabeach sands are reputed to be far from sharp, but among many recently examined for their suitability for use in the paving industry most of them have proved sharper than river or bank sand. Fig. 2, No. 1.

Beach Sands. — *Lakeshore.* — Another form of beach sand is found on the shores of the numerous lakes near some of our large cities, the great lakes in the North, and Lake Pontchartrain in the South.

The assorting of the particles composing lakeshore sands is accomplished largely by the movement of water produced by storms, a more complicated one usually than is presented on the seabeaches, although not as powerful as a rule. Tidal action is of course absent. In many localities the force of the waves or of the induced currents are so small as to permit of the deposition of very fine sand or of that in which the particles are very well graded in size. In other cases there is a great similarity between lake and seabeach sands. The remarkable variation in the size

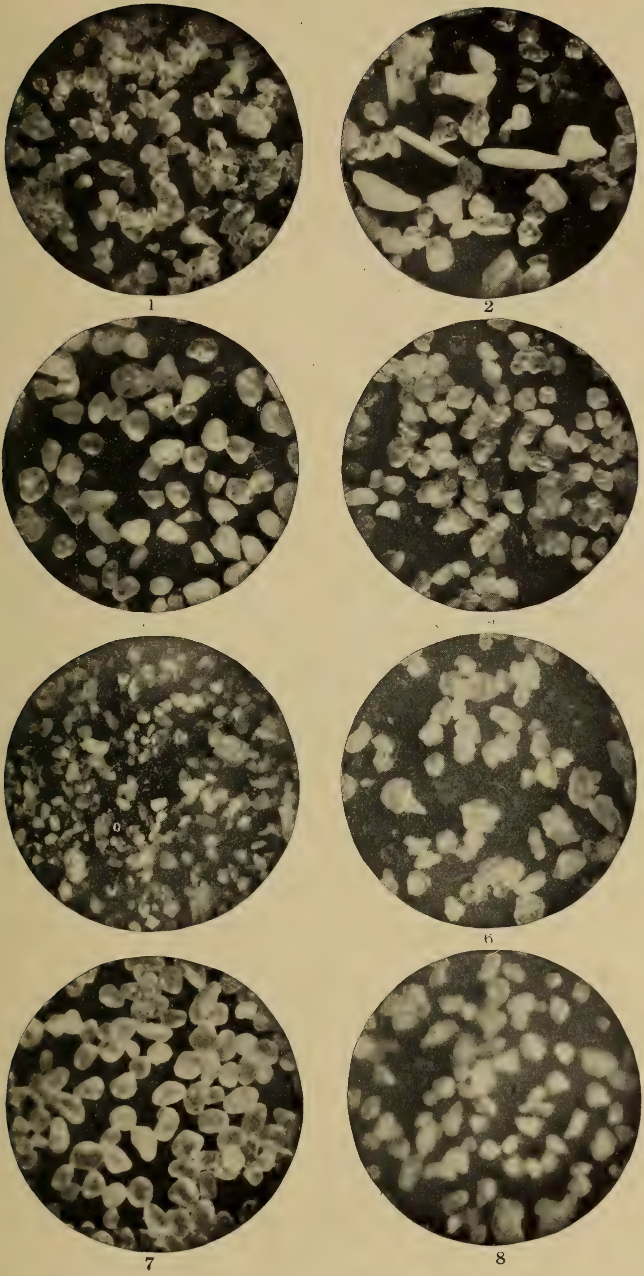

Fig. 2.—Sand Grains.

of lakebeach sand, even on beaches within a few miles of each other, is illustrated by the following examples:

	Lake Michigan.		Lake Erie.
	Kenosha, Wis. 1899.	Chicago, Ill. 1897.	Sandusky, Ohio.
Passing 200-mesh sieve.........	2%	10%	0%
“ 100- “ “	8	68	11
“ 80- “ “	16	15	23
“ 50- “ “	52	3	24
“ 40- “ “	13	3	32
“ 30- “ “	3	1	7
“ 20- “ “	2	0	2
“ 10- “ “	4	0	1
	100	100	100

In the Kenosha sand, although the uniformity of grade is not carried as far as was the case on Rockaway Beach, 52 per cent of the particles are of a size to pass a sieve of 50 meshes to the inch. And, again, we have finer sand from near Chicago of still greater uniformity. On the other hand, near Sandusky a lake sand is available which is of quite varied size of grains. Here the sorting of the sand particles has been limited and the grading is satisfactory for use in asphalt surface mixtures without modification. Where lake sands are of too uniform size two or more sources of supply may be used and mixed in suitable proportions. Other typical beach sands from Lakes Michigan, Erie, and Ontario, which are in the writers' collection, sift as follows:

	Milwaukee Beach.	White Fish Bay, Wis.	Lake Ontario. 1894.	Lake Pontchartrain.	Lake Erie. 1892.
Passing 200-mesh.....	0%	1%	1%	0%	2%
“ 100- “	2	27	2	0	29
“ 80- “	6	32	46	1	14
“ 50- “	32	32	44	28	47
“ 40- “	22	3	3	47	4
“ 30- “	14	2	2	21	2
“ 20- “	14	0	1	3	2
“ 10- “	10	3	1	0	0
	100	100	100	100	100

The very considerable variations in the size of these sands from different sources make it possible, however, by mixing those of different sizes, to produce a sand of any grading that may be desired for a surface mixture, and that, too, without great labor.

A peculiarity of lakebeach sand is the rapidity with which all the sand, which may be of most desirable character for asphalt work, may be removed from any particular locality by a violent winter storm and its place taken by a sand of quite different grading. This is of common occurrence between Chicago and Milwaukee, and no doubt elsewhere, so that the fact that a suitable sand can be found at a particular point during any one working year does not mean that the sand will be of the same grading another year, especially if the storms of an intervening winter have been heavy. The variation in the available sand from year to year in this way makes a decided difference in the character of the asphalt mixture turned out at different times in cities which are dependent on such a source of supply.

Lakebeach sands, originating at old lake levels, may, like alluvial sands, be found at times in banks or pits where changes of lake levels, which are so frequent in geological time, have left them above the elevation of, and at times far distant from, the present water level. For commercial uses these cannot be distinguished from beach sands of more recent origin.

Alluvial Sands include all those which have been moved by and deposited from running water as distinguished from beach sands. They may be found to-day in the beds of streams or along their shores and in banks and pits where they have been left by running water in past geological times. Alluvial sands may also include those originating in glacial streams and occurring both in banks and pits and as reassorted by recent water action. There are also deposits in lakes from streams flowing into them which need not enter into our consideration, being rarely so available as to be of technical importance.

River Sands. — As river sands are conveniently considered those which are found in the beds of streams or on their beaches, and which are still largely subject to the action of water. They are oftener found at the concave side of some bend or at a place where the current makes a change in direction or loses its force. Geikie describes the deposition of river sand as follows:

"While the main upper current is making a more rapid sweep round the opposite bank, under currents pass across to the inner side of the curve and drop their freight of loose detritus, which, when laid bare in dry weather, forms the familiar sand-bank or shingle-beach. Again, when a river well supplied with sediment leaves mountainous ground where its course has been rapid and enters a region of level plain, it begins to drop its burden on the channel."

River sands are usually obtained by dredging and are thus distinguished from bank or pit sand, which are worked from dry deposits. They are most varied in character and form an important part of the supply in use in asphalt paving. In each river they seem to have distinguishing peculiarities, and in no two cities having their source of sand in a river bottom is the supply of the same character, while for any one city the supply may vary in character from year to year.

This may be due to two causes: to the different nature of the rock formations from which the sand found in different rivers is derived and to the different physical conditions to which the débris from these formations has been exposed, resulting in peculiarities of shape, size, surface, etc.

River Sand at Kansas City and Washington, D. C., etc.—River sands are or have been in use in Washington from the Potomac, in Kansas City from the Missouri and from the Kansas, in Omaha from the Platte, and in St. Louis from the Mississippi and Missouri. No two of the sands resemble each other in their behavior in an asphalt surface mixture. The peculiarities which each one shows can be described, but as yet it is impossible to show why they all differ so much in their adaptability to making a desirable surface mixture.

In one of these cities for many years river sands were in use in the surface mixture without the fine bank sand now mixed with it. The river sands would not carry a sufficient percentage of asphalt and made a surface which marked badly under traffic, perhaps more from their coarseness than from other reasons, but which, in comparison with the coarse Washington mixtures of

Potomac River sand, which do not mark in the same way, shows a decided difference in character, not due to the size of the particles of which it is composed.

Two typical surface mixtures from the two cities will illustrate the difference due to the sand. A street in the western city marks up more than most of the pavements in that town, that is to say, badly. The average mixture laid in Washington in 1894 with a straight Potomac River sand scarcely marked at all. The composition of these two mixtures is as follows:

	Kansas City, 1893.	Washington, 1894.
Bitumen	9.9%	10.9%
Passing 200-mesh sieve	9.0	9.9
" 100- " "	6.3	1.5
" 80- " "	5.4	3.7
" 50- " "	36.3	16.1
" 40- " "	10.8	28.9
" 30- " "	8.2	20.7
" 20- " "	6.5	5.9
" 10- " "	7.6	2.4
	100.0	100.0

It would be natural to expect that the Washington mixture with the higher percentage of bitumen and coarser sand would be the softer and mark more than the western mixture, but that is not the case. With a grading not far different and apparently less favorable, the Potomac sand will carry 1 per cent more bitumen than that in use in the West and still not mark in hot weather. The possible difference in sands from different rivers is well illustrated in this case.

As striking differences are to be seen between the mixtures made with river sand in two western cities, which may be denoted No. 1 and No. 2. It is not difficult to get sands in either city which can be properly graded to our present accepted standard and which, it would be supposed, from all appearances would make equally excellent asphalt surface mixtures. On making the mixtures, however, it is found that the river sand at city No. 1 would not hold the usual amount of asphalt cement and that the variations in amount from one box of mixture to another was so great as to make any uniformity in working impossible.

River Sand at City No. 1.—In 1896 an attempt was made to devise a satisfactory mixture for work in this city. A coarse sand was obtained from one river and a fine sand from another. They had the following mesh composition:

Passing 200-mesh sieve	0%	19%
" 100- " "	5	42
" 80- " "	11	19
" 50- " "	42	18
" 40- " "	20	2
" 30- " "	16	0
" 20- " "	4	0
" 10- " "	2	0
	100	100

These sands were combined in such proportions as to make a suitable grading and asphalt cement added until the paper test[1] showed a suitable amount. The mixed sand would hold at the most but 142 pounds of asphalt cement to the 9-foot box of material, and would frequently carry only 126 pounds, and yet the mixture was very sloppy, where a New York mixed sand, weighing about the same per cubic foot, would carry over 160 pounds and stand up firmly.

The grading of the western sand and that from New York, for comparison, was as follows:

	City No. 1.	New York.
Passing 200-mesh sieve	4%	6%
" 100- " "	12	12
" 80- " "	14	12
" 50- " "	37	26
" 40- " "	13	24
" 30- " "	10	8
" 20- " "	5	7
" 10- " "	5	5
	100	100
Weight per 9-foot box, lbs.	846	875
" " cubic foot, lbs.	94	97
A. C. per box, lbs.	126–142	163
Per cent Trinidad A. C. in mixture	13.0–14.0	15.7

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[1] Pages 352–356.

It is impossible at present to explain the difference between the two sands, but it must be one of shape and surface of the grains rather than of volume per cent of voids, there being no great difference between them in this respect.

The use of these sands was abandoned for the reasons which have been given, although the work done with the mixture made at that time has been fairly satisfactory. Such a mixture required too much watching owing to the rapid changes in proportions which were necessary. The experience has proved, however, very instructive and has shown that many mushy mixtures do not prove as bad under traffic as they look when hot, but may give good service; and that the asphalt cement with such sand may be held at a point as shown by the paper stain, which with sand from other sources would be dangerous.

Later the sands in use in this city were both taken from the same river, one being a coarse sand and the other finer. They have been carefully selected by the yard foreman, who has gone out with his sieves on the dredge and taken only sand of a certain grade.

Typical specimens of these river sands sift as follows:

	Coarse.			Fine.		
	1896.	1899.		1898.	1899.	
Passing 200-mesh sieve. . .	1%	1%	2%	20%	17%	25%
" 100- " " . . .	2	5	4	24	40	42
" 80- " " . . .	26	21	22	33	30	21
" 50- " " . . .	42	28	28	17	10	10
" 40- " " . . .	11	20	19	3	1	1
" 30- " " . . .	6	10	10	1	1	1
" 20- " " . . .	8	9	10	2	1	0
" 10- " " . . .	4	6	5	0	0	0
	100	100	100	100	100	100
Retained on 10-mesh sieve	4%					

And the mixed sands as coming from the hopper:

Passing mesh. . .	200	100	80	50	40	30	20	10	
1898.	9%	14%	30%	28%	7%	4%	5%	3%	=100%
	6	10	25	36	9	7	3	4	=100
1899.	10	9	25	9	16	11	9	11	=100
	13	13	18	22	15	9	6	4	=100
	5	7	18	27	21	9	9	4	=100
	17	13	17	18	15	9	7	4	=100

The sands in 1898 and 1899 carried from 154 to 165 pounds of asphalt cement to the 9-foot box and are more satisfactory than those previously in use on account of their greater regularity. The later mixtures have averaged in composition as follows, which may be compared with that made formerly with the unsatisfactory sand:

	Earlier Sand.	Later Sand. First Year.	Later Sand. Second Year.
Bitumen.	9.9%	11.3%	10.4%
Passing 200-mesh sieve.	14.3	13.2	13.0
" 100- " "	9.4	9.7	10.0
" 80- " "	13.3	14.7	9.0
" 50- " "	33.0	37.2	25.0
" 40- " "	10.3	5.7	15.0
" 30- " "	6.1	3.8	8.0
" 20- " "	2.6	2.7	6.0
" 10- " "	1.1	1.7	4.0
	100.0	100.0	100.4

The second mixture of the year 1899, was the most satisfactory of any made up to that time, but even here undesirable features are to be found, which will be considered later.

The peculiarities of these sands are, however, very instructive if at the same time very trying in the asphalt business.

River Sand at City No. 2.—In city No. 2 the river sand presents a most desirable grading, as shown by the following sifting of some in use in July, 1899:

Passing 200-mesh sieve	3%	2%
" 100- " "	26	19
" 80- " "	12	19
" 50- " "	39	41
" 40- " "	14	12
" 30- " "	2	3
" 20- " "	3	2
" 10- " "	1	2
	100	100

This sand is peculiar, however, in that in making a mixture according to our practice it is found that if the asphalt cement is added in amount only sufficient to stain the paper [1] to the same degree as with the sands in other cities, the bitumen in the mixture does not exceed 9 per cent. With a larger amount of asphalt cement, sufficient to yield 10 per cent of bitumen in the mixture, the latter is very sloppy.

This peculiarity might lie either in the heavier volume weight of the sand and the smaller voids or in some characteristic of the surface of the grain which would prevent the usual amount of asphalt cement from adhering to it. It has been found, however, on the use of this same sand in a neighboring city that a satisfactory surface containing as much as 10 per cent of bitumen can be laid by making the mixture as rich as is necessary for this figure, and disregarding the usual indications of richness and overfilling of the voids. The finished surface does not appear to be excessively soft in summer and wears well. This would point to the correctness of the idea that the peculiarity of this sand lies in its surface and perhaps in its shape. Nothing peculiar in either of these respects, as far as can be seen under the microscope, can be discovered, the sand being a nearly pure quartz, having a ground-glass surface with rounded angles. Fig. 2, No. 3.

In considering the subject of mixtures these peculiar sands will be referred to again.[2]

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[1] This paper test will be described later, pages 352–356, 514. It indicates the amount of asphalt the sand will carry.

[2] Page 351.

The river sands of the United States in the Mississippi Valley seem, therefore, to be possessed of peculiar properties which we are unable as yet to account for, and it is necessary to handle them in the paving industry in a different way from other sands, or else to reject them.

Bank or Pit Sands.—Bank or pit sands are deposits of sand which have been laid down in their present position by various agencies in past geological times, as distinguished from the river and beach sands, which have been described and which are the results of the recent assorting of detritus by water action, or by the reassorting of bank sands under changed conditions, which is quite possible, as on the north shore of Long Island, where the glacial bank sands are often reassorted by water action into modern beach sands.

Bank sands are of the most varied derivation—river, beach, glacial, æolian, etc.—including all possible sources of origin. On the Hudson are found banks of river sand, as at Croton; on Long Island banks of glacial sand, as at Cow Bay, and in Sioux City, Iowa, banks of æolian sand in the loess.

Bank sands grade in size from fine gravel or coarse concrete sand to the impalpably fine ones which are found in those wind-blown deposits of a large portion of the West, called loess, and which are often almost entirely a sharp sand composed of quartz particles fine enough to pass a 200-mesh sieve.

To the paving industry the bank sands offer sources of supplies which are more varied in the size of the particles of which the sand is made up than the river and beach sands of recent origin, and are oftener to be obtained of that degree of fineness which has been found to be such an essential feature in our modern mixtures, that is to say, of 80- and 100-mesh size. The varied grading of different bank sands, not including the coarser concrete supplies which are not used in the asphalt industry for surface mixture, is illustrated by the following characteristic specimens (see table, p. 47).

These bank sands, it will be seen, admit of combinations of two or more in such a way as to attain any required grading. Fortunately no bank sands are met with which present any of the peculiarities of the river sands of the Mississippi River Valley. They all carry asphalt well and make good mixtures.

Passing Sieve of Meshes.	New York Supply, 1899.				Boston Supply.	
	Cow Bay.		Corbin's Bank, Steinway.	Delagoa Bay Ballast.	Braintree, Mass.	Canton, Mass.
200	4%	2%	6%	1%	12%	7%
100	7	5	10	60	25	13
80	9	7	12	36	15	14
50	28	24	28	2	29	33
40	22	16	15	1	9	19
30	15	18	13	0	6	6
20	9	13	10	0	2	6
10	6	15	6	0	2	2
	100	100	100	100	100	100

	Buffalo Supply, Attica, N. Y.	Elmira Supply.	Utica Supply.	Lafayette Supply.	Toronto, Ontario, Supply.
200	32%	6%	8%	3%	29%
100	29	7	31	5	36
80	17	38	25	4	14
50	19	48	20	36	13
40	1	1	12	37	2
30	1	0	2	10	6
20	1	0	1	3	0
10	0	0	1	2	0
	100	100	100	100	100

	Kent, England, Glacial.		Louisville Bank.	Sioux City, Loess.
	White.	Yellow.		
200	0%	tr.	48%	99.5%
100	11	4%	20	.5
80	74	28	11	
50	14	62	18	
40	1	6	1	
30	tr.	tr.	2	
20	0	0	0	
10	0	0	0	
	100	100	100	100.0

Many bank sands are unsuitable for use in the surface mixture, however, owing to the presence of too much clay or loam, or to a surface on the grain which is more or less covered with a ferruginous cement, existing in the original rock from which the sand is derived, or with argillaceous matter, to neither of which surfaces does asphalt adhere satisfactorily. The former peculiarity is of the commonest occurrence, but probably only becomes serious when the amount of clay or loam is too large to be taken care of as dust, or is in such a form as to ball up in the sand-heating drums, or not to mix with the asphalt cement properly. A loamy tempering sand has been in use successfully in an Ohio River city for several years. The latter difficulty is typical of the red sands of New Jersey, which have a coating of iron oxide firmly adherent to their surfaces, and the sands found associated with the London gravels which are similarly but not so distinctively coated. From the latter sand a coating of asphalt cement would wash off in a few weeks when exposed to the weather, destroying the surface mixture made with it. The red sands of New Jersey may possibly be used without danger; that from Rutherford has been as a tempering sand, but they do not look attractive and are suspicious.

There are no other noticeable peculiarities of bank sands to be mentioned which, as far as is known, render them unsuited for surface mixtures, except the presence of too much 200-mesh material which consists of sand grains of that size and not dust. Sand of this size is, as a rule, disadvantageous in a mixture and makes it mushy and liable to push or shove under traffic. The peculiarities of mixtures containing much 200-mesh sand will be discussed later.

Quicksands.—Any of the preceding sands is often called quicksand if it is very fine. Quicksands are really of that peculiar nature only when they consist of particles largely finer than will pass a sieve of 200 meshes to the inch and consequently having a small hydraulic value. When such sands have their voids filled or more than filled with water they are unstable and mobile. There is no reason why a coarse sand should not at the same time be a quicksand if it is supported and its voids more than filled by a force of water of sufficient head. It has often been stated that quicksands consist of uniform sized and round particles, but recent examination of some material of this description[1] has shown that they generally consist of sharp grains and are often well graded. Several quicksands have been examined by the writer with the following results, which are characteristic of such material:

QUICKSANDS—BOSTON, 1897; WORCESTER, 1900.

Test No. 11541. Boston—Neponset Valley Sewer. Nat. Contr. Co.
" " 11542. " " " " " " "
" " 11544. " " " " " " "
" " 30723. Worcester—Green Street. H. P. Eddy.
" " 30724. " " " " " "
" " 30725. " " " " " "
Finest-ground limestone, all passing 200 mesh.

Nos. 11541, 11542, and 30725 are clean sands, grains all sharp. Nos. 11544, 30723, and 30724 contain a small amount of clay, less than 1 per cent, not subsiding entirely in one week.

Test Nos.		11541	11542	11544	30723	30724	30725	Finest-ground Limestone.
Voids in hot compacted sand...		29.3%	....	40.2%	36.7%	34.7%	....	39.3%
Weight per cubic foot of same in pounds......		117.2	....	99.1	103.8	106.1	....	100.4
Sieve.	Diameter, Millimeters.							
	.035	19.2%	11.2%	65.5%	47.2%	11.6%	79.7%	63.5%
	.065	7.9	14.2	13.7	19.6	11.4	9.5	17.7
200	.09	18.9	19.6	17.8	11.2	9.0	9.8	18.8
100	.17	34.0	22.0	2.0	13.0	39.0	1.0	
80	.23	11.0	8.0	1.0	4.0	12.0		
50	.31	7.0	16.0	....	3.0	10.0		
40	.50	1.0	4.0	....	1.0	3.0		
30	.67	1.0	2.0	....	1.0	3.0		
20	1.00	....	2.0	....	....	1.0		
10	2.00	....	1.0					
		100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Greater than 2.	....	2.0%					

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[1] Landreth, Wm. B., The Improvement of a Portion of the Jordan Level of the Erie Canal. Trans. Am. Soc. C. E., 1900, **43**, 596.

It is apparent that some quicksands are quite widely graded, others consist to a very large extent of uniform particles smaller than .035 millimeter in diameter (.0014 inch) and even finer than the finest dust in Portland cement. That they are all composed of sharp grains, contain traces only of clay or none, have an extraordinary fineness, in one case greater even than that of the best ground limestone, are their astonishing characteristics.

The angularity of these small particles is explained by their small hydraulic value and consequent freedom from attrition, as shown by some experiments of Daubree, quoted by Geikie, Text-book of Geology, third edition, page 385. He says:

"In the series of experiments already referred to, Prof. Daubree made fragments of granite and quartz to slide over each other in a hollow cylinder partially filled with water and rotating on its axis with a mean velocitiy of .80 to 1 metre in a second. He found that after the first 25 kilometers (about 15½ English miles) the angular fragments of granite had lost $\frac{4}{10}$ of their weight, while in the same distance fragments already well rounded had not lost more than $\frac{1}{100}$ to $\frac{1}{400}$. The fragments rounded by this journey of 25 kilometers in a cylinder could not be distinguished either in form or general aspect from the natural detritus of a river-bed. A second product of these experiments was an extremely fine impalpable mud, which remained suspended in the water several days after cessation of the movement. During the production of this fine sediment the water, even though cold, was found in a day or two to have acted chemically upon the granite fragments. After a journey of 160 kilometers, 3 kilograms (about 6½ pounds avoirdupois) yielded 3.3 grams (about 50 grains) of soluble salts, consisting chiefly of silicate of potash. A third product was an extremely fine angular sand consisting almost wholly of quartz, with scarcely any feldspar, nearly the whole of the latter mineral having passed into the state of clay. The sand grains as they are continually pushed onward over each other upon the bottom of a river become rounded as the large pebbles do. But a limit is placed to this attrition by the size and specific gravity of the grains. As a rule the smaller particles suffer proportionately less loss than the larger, since the friction on the bottom varies directly as the weight and therefore as the cube of the diameter, while the surface exposed to attrition varies as the square of the diameter. Mr. Sorby, in calling attention to this relation, remarks that a grain $\frac{1}{10}$ of an inch in diameter would be worn ten times as much as one $\frac{1}{100}$ of an inch in diameter, and a pebble 1 inch in diameter would be worn relatively more by being drifted a few hundred yards than a sand grain $\frac{1}{1000}$ of an inch in diameter would be by being drifted for a hundred miles. So long as the particles are borne along in suspension, they will not abrade each other, but remain angular. Prof. Daubree found that the milky tint of the Rhine at Strasburg in the months of July and August was due, not to mud, but to a fine angular sand (with grains about $\frac{1}{20}$ millimeter in diameter) which constitutes $\frac{2}{1000000}$ of the total weight of the water. Yet this sand had travelled in a rapidly flowing tumultuous river from the Swiss mountains, and had been tossed over waterfalls and rapids in its journey. He ascertained also that sand grains with a mean diameter of $\frac{1}{10}$ mm. will float in feebly agitated water, so that all sand of finer grains must remain angular. The same observer has noticed that sand composed of grains with a mean diameter of $\frac{1}{2}$ mm. and carried along by water moving at a rate of 1 metre per second is rounded and loses about $\frac{1}{10000}$ of its weight in every kilometer travelled."

These remarks explain some of the characteristics of the quicksands which have been described.

So-called quicksands consisting largely of particles of 100- and 80-mesh size form one of the most valuable sand supplies which can be used in the paving industry. They are known as tempering sands, and when mixed with the ordinary sand produce a grading which is more satisfactory than that of any sand deficient in such fine particles.

Glacial Sand.—Such sands are found on the north shore of Long Island and are largely used in the paving industry in the city of New York. Fig. 2, No. 4.

In those parts of the country which were covered with the ice sheet during the Glacial Period a large part of the beach, lake, and river sands may consist of glacial material reassorted by more recent water action, but this is, of course, not true of sands from regions south of the terminal moraine, nor is it probably the case with the sands found in our western rivers, which are of very recent origin. This may account for the fact that the sands from the Mississippi and Missouri Rivers and their tributaries are so different from many other river sands.

Sands Derived from Sandstones.—Supplies of sand are to be found at times which are obtained by grinding and breaking down loose sandstones of little coherence. These sands are largely used in glass-making and are usually very fine quartz. They have been offered in several cities for paving purposes. Two samples sifted as follows:

Passing 200-mesh sieve	5%	5%
“ 100- “ “	7	15
“ 80- “ “	13	22
“ 50- “ “	45	40
“ 40- “ “	25	15
“ 30- “ “	2	1
“ 20- “ “	1	1
“ 10- “ “	2	1
	100	100

They have never been utilized in the paving industry.

Artificial Sands.—The finer material produced in crushing rock for the purpose of obtaining broken stone for concrete when screened to a proper size is a sand. It differs essentially from the natural sands in that it has not been subjected to weathering or attrition and consequently is sharp and has a rough surface. Fig. 2, No. 5. It is generally well graded through different sizes and has low voids. Specimens of such a sand are represented by the screenings from the crushing of granite, gneiss, limestone, and trap in various parts of the East, which sift as follows:

Test No. 68417. Crushed gneiss screenings from Jerome Park Reservoir, New York.
“ “ 66563. Trap-rock screenings, Nyack, N. Y.
“ “ 62082. Limestone screenings, Muskegon, Mich.
“ “ 64840. “ “ Owosso, Mich.
“ “ 69721. “ “ Harrisburg, Pa.
“ “ Washington, D. C.

Test number.	68417	66563	62082	64840	69721	——
Passing 200-mesh sieve. . .	6.5%	10.5%	17%	7%	28%	21%
“ 100- “ “ . . .	7.5	7.5	3	5	12	14
“ 80- “ “ . . .	5.0	2.5	. . . .	4	7	8
“ 50- “ “ . . .	12.5	7.0	. . . .	8	13	11
“ 40- “ “ . . .	12.5	4.0	. . . .	5	9	8
“ 30- “ “ . . .	8.0	5.0	. . . .	5	9	6
“ 20- “ “ . . .	10.0	5.5	. . . .	6	11	8
“ 10- “ “ . . .	8.0	15.5	52	18	11	19
“ ¼-inch “ . . .	17.0	34.0	28[1]	42	0	5[1]
“ ½- “ “ . . .	3.5	8.5	. . . .	0	0	
“ 1- “ “ . . .	9.5	0.0	. . . .	0	0	
Retained on 1-inch sieve .	0.0	0.0	. . . .	0	0	
	100.0	100.0	100	100	100	100

[1] Retained on 10 mesh.

These screenings are of excellent character for use in hydraulic concrete and have also been successfully made part of the mineral aggregate of surface mixtures, as the finer material which they contain is very desirable in localities where the particles of the same size are not found in the native sand.

The screenings from the softer limestones of the middle and far West are not so desirable as a substitute for native sand, and no attempt has been made to use them in an asphalt-surface mixture as sand. When ground they form a most desirable filler, as they readily become impregnated with asphalt.

Purchase of Sands.—In this connection it may be well to state that no sand is desirable for use in an asphalt-surface mixture which would be considered suitable for use in lime or cement mortar. It is therefore often difficult to explain to sand-dealers the kind of sand needed in the asphalt industry and more often difficult to find it, as there is no demand for such sand from others and consequently little inducement to open up or develop pits or supplies of the proper kind. It is well usually to say, in asking a sand-dealer for sands for surface mixtures, that one wishes a sand that is too "soft" for any other use, and that one which is suitable for mortar would be of no value for pavements.

Composition.—The composition of a sand, as long as the grains are hard, cannot seriously affect its availability for use in an asphalt-surface mixture or be a cause of defects in it. Soft-grained sand should be rejected when this is possible. The grains of a very large majority of all the sands in use in the asphalt industry, in fact of almost all natural sands, are composed of quartz, the silicates, feldspar, etc., being decomposed and removed from the detritus of the original rock by weathering or water action. The character of the quartz may vary largely, however. It may be a clear, transparent, hard quartz, a softer cloudy-white quartz, or an even softer ferruginous one. The two latter suffer more from attrition, have round forms and dead surfaces. Rarely sands are found which consist of a large proportion of silicates or of shales, although a small amount of magnetite and the harder pyroxenes are to be detected in most sands. Potomac River sand often carries 3 per cent of magnetite, and that from Siboney beach, which has been used in Santiago, Cuba, must consist fully half of hard silicates such as hornblende and similar minerals, which are, however, not unsuitable for paving purposes. A sand formed by weathering of a granite rich in feldspar on Cape Neddick in Maine is largely made up of coarse particles of feldspar, but it is not of any practical importance.

The sand found in the Mohawk and Hudson River Valleys from Poughkeepsie to Geneva consists largely of small oval and flat particles of shale, although some quartz is present. These sands are, of course, comparatively soft, but good work for light traffic has been done with them.

Calcareous sands are rather unusual, except those derived from shells and the detritus of coral. Limestones weather out or dissolve too rapidly in water to permit of the formation of sand, although they are found to a certain extent in admixture with quartz sands at many points.

Coral and shell sands are common in southern latitudes, as in Cuba and Bermuda, for instance. They are the softest sands that are met, usually crumbling under moderate pressure. Few particles finer than 80-mesh size are found in the coral sands, as these are readily washed away and dissolved. The shell sands of Cuba are firmer than the coral sands.

Mixed sands composed of quartz and silicates, and quartz and carbonates, occur. Such include the more evenly proportioned Siboney beach sand and the shale sand of Northern New York. The lake sands often contain considerable carbonates in the form of shells, and a small amount is found in almost all. Determinations of lime in several supplies, made in 1896, gave the following results:

Source of Sand.	Per Cent CaO.
Buffalo—lake	9.3%
New York—bank	2.2
St. Louis—river	.8
Kansas City—river	.2
Boston—bank	.2

Their presence has no injurious influence on the sand as far as its use in asphalt surface mixture is concerned. Asphalt cements probably adhere better to limestone than to silica or silicates, and in this way it may be desirable.

It is sometimes of interest to determine how much or what percentage of a sand is in a condition soluble in strong acid, such as hydrochloric. The amount found in the sands mentioned above, which were examined for lime, was as follows:

Source of Sand.	Per Cent Soluble.	Per Cent Iron Oxide and Aluminum.
St. Louis—river	2.2%	.9%
Kansas City—river	2.4	1.4
New York—bank	3.4	2.3
Boston—bank	3.6	2.4
Buffalo—lake	12.9	1.5

In the ordinary run of sand this is small and of no importance. In some of the sands, like the red sands of New Jersey, it is indicative of a weakness in the material.

Sands may often carry admixtures of substances which cannot be considered as part of the original material from which they have been derived but which are adventitious in some way or other. Clay and loam are the commonest substances and their presence is accounted for in two ways. Either they are intimately mixed with the sands in the deposits, as in the fine bank sand mentioned as being used for tempering purposes, or they exist in strata covering or adjacent to the sand and are unavoidably mixed with it in collecting the latter. If not adherent to the grain a small amount will act merely like the dust added to the sand before the asphalt cement, but if the clay or loam balls in the drums and is not screened out it may prove injurious. A clean sand is in any case probably more desirable, although satisfactory results have been obtained with many loamy ones.

Organic matter in the shape of vegetable débris is sometimes found in sand. It is usually removed in screening the hot sand as it comes from the drums. If this is not possible and the amount remaining is excessive the sand should be rejected.

Shape of Sand Grains.—The shape of the grains of which sands are composed is quite varied.

Irregular Grains.—Fresh detritus from the original rock is generally irregular in shape and with sharp angles unless it is derived from a rock composed of grains which have already existed as sand. Sands formed of irregular grains are not common, but they are often found with the grain quite irregular in shape but the angles somewhat rounded by water or glacial action. The sands from the north shore of Long Island are of this class. Fig. 2, No. 4, shows the peculiarity of the grain. They are of very irregular shape with re-entrant angles, but are slightly rounded with loss of the sharpness of the original fragment.

Crystalline Grains.—Sands containing crystals are mentioned by Sorby. They have been met with by the author but once in the United States. In a sand supply used in Atlanta, Ga., some years ago, there could be detected with a glass quite a large proportion of well-shaped quartz crystals some of which were twins. Fig. 2, No. 6, shows the irregular weathered crystals forming this sand.

Such sands are undesirable for an asphalt surface mixture for reasons too obvious to require mention.

Oval Grains are worn much more smooth by continued water, tidal or glacial action, the original angles being mostly or entirely lost. Tidal action has a peculiar tendency to produce grains with one diameter longer than the other, as particles with this peculiarity arrange themselves with their longer diameter in the direction of the force of the waves and are then worn still more into this shape. Seabeach sands are supposed on this account to be far from sharp, but that on the Florida beaches is markedly so. Fig. 2, No. 1.

Round Grains.—Round-grained sands are not uncommon. They are oftener found in river, glacial, and æolian sands, which are worn by being rolled over and over and polished against each other like the well-known spheres of quartz prepared by the Japanese. Fig. 2, No. 7. It is probable that a very large percentage of sand is composed of the somewhat irregular, rounded grains.

The shape of the grains of a sand has a marked influence, when combined with their size and grading, upon the character of the asphalt surface mixture made with them, the closeness with which they can be packed together depending to a very considerable degree on their shape. Round sands and oval sands can be compressed much more readily than sharp ones, owing to the smaller friction between the smooth surfaces, although they may not on this account be found to pack as closely eventually. Whether the shape of the grains in the sands in use in paving mixtures has any effect sufficient to account for the cracking of some surfaces more than others is a question for investigation. It may so influence the character of the voids in a mineral aggregate as to do so. This will be considered later. Mixtures made with round-grained sands are of course less stable and mark more easily in summer than those made with sharp sand, since round particles move much more readily over one another than sharp ones; but, on the other hand, with plenty of filler this tendency can be neutralized, while the round-grained sands can be packed much more readily and closely and with smaller voids and the resulting surface can, in this way, be made denser.

Surface of Sand.—The character of the surfaces of sand grains is very different, much more so than would appear from mere ocular examination. Under the microscope sand grains are found, as shown in our classifications, with the surfaces of the original material of which the grains are composed, or with the surfaces derived from fracture of this material. There are surfaces polished by attrition and water action, surfaces like ground glass, Fig. 2, No. 7, originating in the same way, surfaces coated with the cementing material originally uniting the grains into a sandstone, surfaces acted upon chemically, and the porous surfaces of limestone and coral grains. The different kinds of surfaces behave quite differently toward asphalt cement. The porous limestone surfaces absorb it and it, of course, adheres very firmly. To the quartz surfaces the bitumen adheres in most cases well, but in others only slightly, being readily washed off with water. Some quartz grains will carry a heavy coat of asphalt cement, others but a small and thin one, as can be detected by examining with a glass mixtures made with different sands.

These peculiarities can be explained by the difference in the capacity of surfaces of different character for retaining or adsorbing bitumen, the film adhering being thicker in one case than in another. They have a very decided effect upon the character of different mixtures and may well be the cause of cracking in surfaces made with certain kinds of sand. As has been already remarked, a sand from the London gravels has a surface such that asphalt cement would not adhere to it in the presence of the dampness of a London fog, so that it would be found in the gutters after a rain, washed quite clean and free from bitumen.

That even water has strong chemical effect on the surface of sands, thus altering its character, can be seen from Daubree's experiments already alluded to. Geikie quotes him as follows:

"Daubree endeavored to illustrate the chemical action of rivers upon their transported pebbles by exposing angular fragments of feldspar to prolonged friction in revolving cylinders of sandstone containing distilled water. He found that they underwent considerable decomposition, as shown by the presence of silicate of potash, rendering the water alkaline. Three kilograms of feldspar fragments made to revolve in an iron cylinder for a period of 192 hours, which was equal to a journey of 460 kilometers (287 miles), yielded 2.720 kilograms of mud, while the

5 litres of water in which they were kept moving contained 12.60 grams of potash, or 2.52 grams per litre."

Of course quartz grains are not attacked like the feldspar, and it is for this reason that in sands resulting from the decomposition of rocks containing feldspar none of the latter remains and the grains of which it is composed are all quartz, hornblende, etc.

From what has been said in the preceding paragraphs the very variable character of sand, apart from the size of the grain, will be readily understood. All of these characteristics demand careful consideration in the selection of sands for successful asphalt surface mixtures. But more important even than these considerations is the size of the grains which go to make up any sand.

Size of Sand Grains.—The size of the sand grains in an asphalt pavement, that is to say their average diameter, is of the greatest importance, as will be found in studying the subject of surface mixtures. Sands occur in nature in which are found every size grain from the impalpably fine quartz of silt to fine gravel. In a standard sheet asphalt surface it has been found generally preferable to have no sand grains larger than 2 millimeters in diameter, passing a 10-mesh sieve made of wire .027″ in diameter, or smaller than .17 millimeter, which pass a sieve of 100 meshes to the inch, made of wire .0043″ in diameter. It is always possible to exclude the coarser grains, but it is not so easy to get rid of the material which is too fine.

Sands are differentiated into various sizes by means of sieves somewhat arbitrarily made, but so selected for use in the asphalt industry that the average diameter of the particles shall bear a definite relation to each other. The finest sieve in use, 200 meshes to the inch, made of wire .00235″ in diameter, passes particles of all degrees of fineness up to a diameter of .10 to .083 millimeter. The coarsest particles passed by this sieve are plainly sand and are generally round and usually undesirable. The next sieve in use has 100 meshes to the lineal inch and is made of wire .0043″ in diameter. It passes particles having a diameter of about .17 millimeter, or double that of those passing the 200-mesh sieve. The next, made of wire .00575″ with 80 meshes, passes particles of a diameter of .23 to .24 millimeter, three times that of the 200;

the next, made of wire .0090″ in diameter, 50 meshes, particles of about .37 millimeter, or four times the finest sieve. The 40-mesh sieve, made of wire .01025″, however, passes at a jump to a particle six times the diameter; the 30, made of wire .01375″ in diameter, to one of eight times; the 20, made of wire .01650″ in diameter, to one of about twelve, and the 10, made of wire .027″ in diameter, to one of about twenty to twenty-five times the diameter of the largest grain passing the finest sieve. A more minute differentiation than this of the size of the sand grains would be burdensome and of no advantage. For this reason sieves of 150, 90, 70, and 60 meshes to the inch are not used in the paving industry. As an example of the use of these sieves the great difference between the size of the particles of a sand suitable for hydraulic concrete and that suitable for an asphalt surface mixture will serve and is seen to be quite marked. In the former a coarse sand is sought, in the latter a fine one.

	Hydraulic Concrete Sand.	Paving Sand.
Passing 200-mesh sieve	Trace	—
" 100- " "	1%	17%
" 80- " "	2	17
" 50- " "	17	30
" 40- " "	18	13
" 30- " "	24	10
" 20- " "	22	8
" 10- " "	16	5
	100	100

It will be observed in the above siftings that the results are stated in percentages of the material passing the various sieves. This method of statement is much to be preferred to that in which the percentages remaining on the different sieves are given, and for two reasons. In the first place it enables one to judge of the size of the grains from the diameter of the meshes and the size of the particles passed by such a mesh, which cannot be done from the percentage remaining on the sieve. In the second place, as will appear from the description of the method of making a sifting in Chapter XXVIII, it is much more easy to remove the fine material which passes the 200-mesh sieve by attrition of the coarser grains one upon another and upon the cloth of the sieve than to separate out the coarser grains first and afterwards weigh the remaining 200-mesh material, especially as there is apt to be a loss of this material during the process of sieving, which makes no difference if it is sifted out first and the amount determined by loss.

The sieves which are used for the sifting are carefully made in large lots by one firm from the same lot or roll of cloth woven for the purpose, so that several sets shall be so nearly alike as to give uniform results even in different hands.

COMPARISON OF THE SIEVING OF TWO SAMPLES OF SAND ON DIFFERENT SETS OF SIEVES IN DIFFERENT LABORATORIES.

Sample number.	1		2	
Siftings.	Lab. No. 1	Lab. No. 2	Lab. No. 1	Lab. No. 2
Passing 200-mesh sieve. .	15%	15%	10%	10.5%
“ 100- “ “ . .	25	25	15	18.9
“ 80- “ “ . .	12	12	17	10.5
“ 50- “ “ . .	28	26	33	34.7
“ 40- “ “ . .	8	11	10	11.5
“ 30- “ “ . .	5	5	5	6.3
“ 20- “ “ . .	5	5	6	3.2
“ 10- “ “ . .	2	1	4	3.1
	100	100	100	98.7

While the agreement in the siftings obtained with sieves made in this way is as concordant as could be expected a similar agreement will not be found among sieves obtained from different sources, especially in the case of the finer ones with 80, 100, and 200 meshes to the linear inch. In explanation of the difference in the character of the cloth woven by the different manufacturers Messrs. Howard & Morse, of Brooklyn, N. Y., who manufacture the sieves in use by the author, have the following to say in reply to certain questions which were propounded to them.

In reply to the inquiry as to where the cloths in use for making these sieves are manufactured they state that:

"Wire cloth of iron, steel, brass, or copper, from the coarsest to No. 100 mesh, is made in this country, while the finer meshes are imported from France, Germany, and Scotland. We think the Scotch cloth is the best. Even 100 mesh can be imported at a lower cost than the rate paid our weavers will allow it to be produced. . . . We do not believe any American manufacturer could be induced to make the necessary outlay to produce cloth finer than 120, unless the field for its usefulness was very much enlarged, as the imported cloth at a much lower cost seems to answer every general purpose for which such cloth is used. Moreover it might be necessary to import the workmen."

As regards the process of manufacture they say:

"Beginning with wire, say, $\frac{1}{16}''$ in diameter, the mill draws down to smaller sizes until too hard to safely draw smaller; it is then annealed, when, its ductility being restored, it is drawn down finer, and then reannealed, and the process repeated until the requisite size is obtained and it is given its final annealing, to render it fit for fabrication into cloth. The wire is delivered by the mill to the wire-cloth manufacturers in skeins, which are rewound on spools according to the mesh required. Usually the process is as follows:

"Take for instance 100 mesh. We desire to put on a 'warp' say 36″×300 feet. This will make 3 'cuts' each 100 feet long. We estimate the weight, allowing for waste and 'thrums,' and taking a little over one-half the total weight, we divide this as equally as we may among the 100 spools, being careful that none are under weight. The spools are placed in a rack as closely as convenient; the wires from each spool are led through a device which prevents their crossing (and serves other purposes of a nature somewhat complicated to explain) to the 'back-beam of loom.' The 100 wires are what we term an inch. They are tied together at the end and hook over a bolt-head in a slot which runs lengthwise of the beam, which in our looms is about 5′ circumference and 52″ long. For 36″ width we hook our first inch on peg 18″ from centre. For 300 feet we would need to put on 60 'rounds,' i.e., the beam (which is really a heavy hollow cylinder) is turned 60 times, and the 'lease' wire separating the contiguous wires alternately above and below is put in place and the beam turned up one more revolution to allow for distance from back-beam to face of loom.

"The inch is then secured to another peg, which is firmly secured in the partition between the inches, these partitions forming 'grooves' in which the wires lay, and the bunch of 100 wires is then cut off and the second groove receives its 60 rounds, and so continued till the 36 grooves or inches are filled. This is a slow, tedious process.

"However careful may be the windings of the spools, whatever device may be used for spool racks, yet the wire will catch and break, and it is necessary to repair every break before another round is turned up on the back-beam. If the spools run too freely, the wire comes off too fast, and a 'bight' will draw into a kink and snap even with comparatively heavy wires, or the bight will lay across other wires and catching may snap a dozen or more. However, the warp being on the back-beam, one inch is taken off the peg, and the wires, being separated by the 'lease,' are passed each one in the order in which it lies in the grooves, first through the 'gears,' or 'heddles,' and next through the 'reed.' The heddles consist of two frames about 8 to 10 inches high by the width of the loom in length, secured in a variety of ways; to these frames are attached twisted wires with an eye in the centre. For 100 mesh each frame must contain at least 50 of these twisted wires to each mesh. The 100 wires we have loosed from the back-beam are passed in their exact order alternately through back and front gear, or rather 50 are passed through the eyes of the back-gear and the other 50 passed between the wires of the back-gear through the eyes of the front.

"These gears being operated by treadles, it is evident that when the back-gear is down and the front one is up from the normal line in which wires would tend to lie, that a 'shade,' or shed, is formed, every alternate wire being in the upper, while the others are in the lower shade, or shed. The shade at the gears may be 3″, while at the face of the cloth it is nil, and in front of the reed when swung back as far as the lay will carry it may be 2″. The lay, or 'beater,' is hung overhead and is provided with a groove in what is known as the bottom shell, and also in the top shell, which is removable and adjustable vertically to suit reeds of various heights, which are so placed in the shells as to have free lateral play, but very little in any other direction. All the inches being successively passed through the gears and reed, they are properly fastened to a 'sacking' which leads from the face of the reed around a 'breast-beam' down to the 'cloth-beam,' on which it is wound up as the cloth is made.

"The reed consists of a series of 'splits' made of flat steel of peculiar temper. In a 100-mesh reed they would probably be about $\frac{3}{16}''$ wide, and the thickness of each split would be equal to a trifle less than the space between the wires of the cloth. They are compacted into reeds by a process of lacing, which must be very particularly done, as the split must stand square to plane of cloth, parallel, and evenly spaced, the spaces being a trifle more than the thickness of the wire which passes through them and there must be exactly 100 in each and every inch. The warp being already to commence weaving, the weaver, stepping on the treadle, opens his shade and throws his shuttle through, catching it on the other side of the piece, the lay is brought up one blow and he changes his treadle and gives a second blow to place the shot. After throwing 100 shots and giving 200 blows he has completed 1 inch, when he proceeds to count it and thus discover whether he is driving the 'woof,' or 'filling,' up too hard or too lightly to place 100 transverse wires in 1 inch.

"Until fairly started his warp-wires will be constantly breaking in fine cloth, and it is a constant contest of patience, with unavoidable delays, until the last shot is thrown, though always worse at the beginning and gradually diminishing. After 2 or 3 inches have been made the weaver gets the 'blow' necessary to secure the required fineness in the mesh, and many become very expert and exact; that is, we thought it was exact until Mr. Richardson called our attention to many inaccuracies and defects. Being as good (perhaps better) than similar work from other factories, it sold and we heard no complaint of inequalities until this cement testing question brought us face to face with a different problem."

The size of the wire with which any cloth is made will of course have a decided influence on the width of the meshes of the cloth for any given number per lineal inch. Messrs. Howard & Morse state that while cloth of the same mesh can be made of many different sizes of wire, as shown for the coarser sieves by the ordinary trade catalogues, the difference is more theoretical than practical when we go beyond the 60- or 70-mesh sieves. For the four finer sieves in use in the asphalt-paving industry the diameter of the wire, the mesh, and the space between the meshes are intended to be as follows:

Mesh.		Mesh.	Diam. of Wire.	Space.
No. 50	No. 35 O. E. gauge wire. . .	.02	.009	.011
“ 80	“ 38 “ “ “ . . .	.0125	.00575	.00675
“ 100	“ 40 “ “ “ . . .	.01	.0043	.0055
“ 200	“ 42½ B. & S. wire.	.005	.00235	.00265

In reply to the question as to why the ordinary cloth is much more regular in the number of meshes to the inch in the one direction than it is in the other the makers of the sieves say:

“If the reed be exact the cloth must have the proper number of holes one way, as it is governed by the reed. The reason that cloth sometimes has fewer holes the other way is that it is governed by the blow given by the weaver. If he can pass coarse cloth under the eye of the inspector, he gains the few missing shots in each inch and the same number of blows may in a day's work gain him 5 to 10 per cent more pay, but it is not so often the intention of the weaver so to deceive. A warp of 100 may be put on the loom in December and not be out until the following June. It is slow work. Consider the effects of various temperatures and other causes which may affect a man's disposition meanwhile. Too gay or cheerful, you would be obliged to check his blow which would drive cloth too fine. In brisk, cool weather cloth would be driven up finer than in warm, uncomfortable weather. Again, a fresh start in the morning means better cloth than that made in the later hours of the day. We have been accustomed to pass a coarseness not exceeding 5 per cent; i.e., we would accept 80×76 as a square mesh. Again, the wire is not even in either temper or size.

Hard wire or wire a trifle larger than it should be will not 'go to place' with the same blow that soft, proper gauge wire would require. We select all wire as carefully as possible, and though a great difference is not common in a single skein, yet the writer has gauged a skein of brass wire which has shown a full size difference when gauged at both ends. Not being wire-drawers, we are at a loss to account for this. It seems almost impossible that a die should be worn so perceptibly in drawing less than a mile of wire, and yet one end of the skein may be round while the other is elliptical in cross-section. These causes and others all tend to an irregularity of mesh which shows that the weaver is not entirely at fault.

"To eliminate any question of nicety of touch and skill on the part of the weaver, fortunes have been sunk in experiments to produce an automatic loom; but the other causes remain, and though they affect the accuracy to a less degree in a power loom, yet they have a strong influence. We have power looms that will make the cloth exact, but cannot use them for anything finer than 20 or 30 mesh, and with only a medium-weight wire. Another cause that may affect the mesh is the inequality of 'temper,' or in other words, speaking of other metal than steel, we should perhaps say, 'malleability,' hardness, or softness, but we have come to use the word 'temper,' however incorrect it may be, in reference to all metals used in fabrication of wire cloth.

"The degree of heat to which wire is subjected in the annealing process may vary with the different charges; more than this, it may vary with the heat applied to the different skeins in a single charge, and more troublesome still, it may be hotter on one side of the skein than on the other. This makes serious inequalities in the 'temper' and in consequence a variation in the mesh of the cloth in which it is to be used."

Messrs. Howard & Morse also add as a reason for the great variability in the sieves offered by the trade:

"That each wire-cloth manufacturer has ideas of his own as to what the trade requires; for instance, he may use 48 reed for 50 mesh and have his cloth driven up to 44 the other way, so that he will furnish you on your call for 50 mesh a piece 48×44, while the manufacturer who gave you 50×50 on your call gives you a cloth that costs him more, both for material and labor than the other.

"Again, certain trades, notably the paper trade, requires cloth not driven up square, and 48×38 passes for 50 mesh, 68×52 for 70 mesh, and if this cloth passes through other channels, as a dealer's hands, he will sell a piece to any transient customer, say 58×46, and call it 60 mesh, and with entire innocence, for he bought it for 60 mesh.

"Mill strainer cloth is another irregularity. It is made of very light wire and not driven up with any approach to accuracy. In fact the low price obtained for it prohibits care in its manufacture. It is either woven by boys or on a power loom, which, as explained above, will not insure accuracy in fine meshes."

The Committee on Uniform Tests of Portland Cement of the American Society of Civil Engineers at one time hoped that all sieves in use in the testing of cement might be constructed of wire the diameter of which should be one-half the width of the opening. If sieves could be constructed on this plan it would no doubt be very desirable, but in response to an inquiry as to whether this could be done the manufacturers make the following statement:

"To make fine brass cloth with the diameter of wire one-half the width of opening would result in a flimsy fabrication which in use would give you more unsatisfactory results than you now attain.

"The individual wires would be of very little use and not only break very easily, but would push to one side or the other; two contiguous wires crowding each the neighboring wire would separate and give space four times the size natural to the mesh. We find that in order to make a fairly rigid cloth it is necessary that the diameter of wire be about 80 per cent of space size, or practically as shown in table on page 65. To make the lighter wire would increase cost, though we presume that is of minor importance, and yet it must be considered. It would be difficult to make this perfectly clear perhaps. To take a sample case of frequent occurrence: Our customers know that in the coarse grades of cloth for a certain mesh the price diminishes as diameter of wire decreases, and this is true up to about 60 mesh. We make this from stock of No. 36 O. E. gauge wire (.0075″). They order No. 37 in hope of obtaining it at a lower price per square foot. The weight of 60 of No. 37 is 75¼ per cent as great as the weight of 60 of 36; and yet material for 37 costs about 40 per cent more per pound than 36. This difference becomes greater as we advance to the finer sizes. No. 200 mesh is made of .00235″ wire (as near as the micrometer gauge will show it). The finest wire the writer ever saw was silver .002″ in diameter, and this was shown as a curiosity rather than of any practical use.

"It may be that the ductility of brass is sufficient to make it practicable to draw it to .0017″, but we doubt it, and at what expense? 105,263′ to one pound, i.e., to draw one pound .0017″ brass wire about 20 miles of wire must pass through the dies. This is getting down to fine work. It means about sixteen days' work to one pound, and the finer the wire the more slowly it must be drawn. We do not mean weight, for that is evident, but as regards length. Imagine, too, the making of the die. Can one expect it to be round, square, or true to any regular shape, or exactly accurate with regard to size?

"Take even our 80 mesh, the wire wherein is .00575″ in diameter, nearly 3½ times the diameter of the wire you specify for the 200 mesh, 11½ times as large in area of cross-section, consequently 11½ times as heavy in a given length, and contemplate the skill required to make a hole in a die which shall be round and with an exact diameter smaller than the hole in 100-mesh cloth. Consider the care necessary in drawing this wire, constant watching to note when the die is worn too large, and the whole manipulation until wire is woven into cloth and put into sieves, and there will be apparent reasons sufficient for the inaccuracies noted by you from time to time.

"Up to 100 mesh we can make a cloth as accurate as any one in the trade; beyond that we cannot control it. We will write parties in Glasgow in a few days, and if we can learn anything of interest to you will be glad to communicate it to you.

"We are willing to put on a short warp, say 36″×100 feet each Nos. 50, 80 and 100 mesh, guaranteeing that it shall be driven up square, i.e., the 50 to between 48 and 50, and the 80 between 77 and 80, and the 100 to between 97 and 101, the wire carefully selected to conform to size given in answer to No. 5 (see table on page 65), within 2 per cent of diameter, provided you will agree to find sale for same, at list price net, within one year of completion.

"We are aware that we are undertaking a hard piece of work. The delays will be expensive; we shall expect to pay more than the usual price for the wire; every skein will need to be gauged at both ends, and if long, in the centre as well; much of the wire will have to be discarded; the mill contests our claims of inaccuracy; the cloth will have to be carefully and constantly watched, and the supervision will be onerous, but we are desirous of giving you all the satisfaction possible, though naturally without pecuniary loss to ourselves, and we therefore do not consider the whole cost of supervision in naming the above price."

The preceding explanation will enable the reader to grasp the difficulty of obtaining satisfactory sieves more readily than anything that could be said by the author, and it will show the care which is used in order to obtain, for use in the asphalt industry, sieves which are at least uniform among themselves and which can be considered as standards, at least arbitrarily if not absolutely.

That a better grade of 200-mesh cloth can be obtained which is much more regular than the average supply can be seen from the accompanying illustration, Fig. 3, where the good can be distinguished from the poor cloth without difficulty, and where it can be seen that the lack of regularity is due to the manner in which the weaver pushes up the wire.

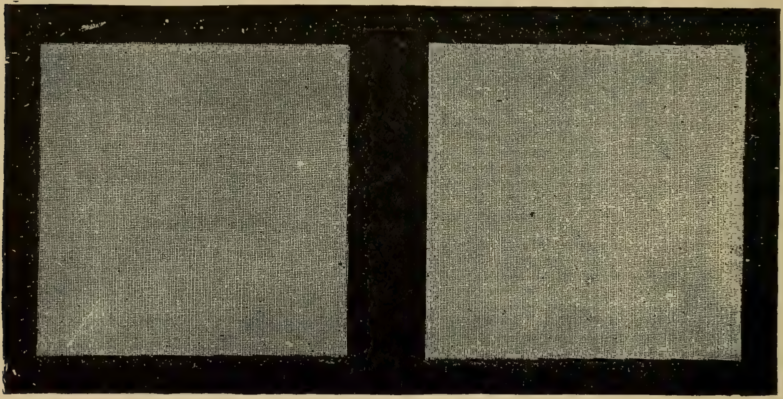
Until 1907, the 200-mesh cloth was twilled, but since that time Messrs. Howard & Morse have produced a plain woven cloth, which in some ways is more satisfactory as far as the number of meshes per inch is concerned, but will probably not wear as well as the twilled material. Three counts of this cloth recently made, resulted as follows:

	Warp.	Woof.
First piece	200	197
Second piece	200	197
Third piece	200	198

while the 100-mesh cloth made at the same time with great care counted

	Warp.	Woof
First piece	100	98
Second piece	100	102

These counts are much more satisfactory than those which were formerly obtained.



Good Cloth. Poor Cloth.

FIG. 3.

The sieves are generally known, as has appeared in what has been said, by the number of meshes which they show to the linear inch. For strictly scientific purposes they would be more properly identified by the diameter of the largest particle which each sieve would pass, and these diameters have already been given for the sieves which are in use in the asphalt industry. For the purpose of determining this diameter Mr. Allen Hazen adopted a method which he describes as follows:[1]

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[1] Twenty-fourth Annual Report of the State Board of Health of Massachusetts, 1892, 541.

"It can be easily shown by experiment that when a mixed sand is shaken upon a sieve the smallest particles pass first, and as the shaking is continued larger and larger particles pass, until the limit is reached, when almost nothing will pass. The last and largest particles passing are collected and measured, and they represent the separation of that sieve. The size of separation of a sieve bears a tolerably definite relation to the size of the mesh, but the relation is not to be depended upon, owing to the irregularities in the meshes and also to the fact that the finer sieves are woven on a different pattern from the coarser ones, and the particles passing the finer sieves are somewhat larger in proportion to the mesh than is the case with the coarser sieves. For these reasons the sizes of the sand grains are determined by actual measurements regardless of the size of the mesh of the sieve. . . .

"The sizes of the sand grains can be determined in either of two ways: from the weight of the particles or from micrometer measurements. For convenience the size of each particle is considered to be the diameter of a sphere of equal volume. When the weight and specific gravity of a particle are known, the diameter can be readily calculated. The volume of a sphere is $\frac{1}{6}\pi d^3$, and is also equal to the weight divided by the specific gravity. With the Lawrence materials, the specific gravity is uniformly 2.65 within very narrow limits, and we have

$$\frac{w}{2.65}=\frac{1}{6}\pi d^3.$$

Solving for d we obtain the formulæ

$$d=.9\sqrt[3]{w},$$

when d is the diameter of a particle in millimeters and w its weight in milligrams. As the average weight of particles when not too small can be determined with precision, this method is very accurate, and altogether the most satisfactory for particles above .10 millimeter; that is, for all sieve separations. For the finer particles the method is inapplicable, on account of the vast number of particles to be counted in the smallest portion which can be accurately weighed, and in these cases the sizes are determined by micrometer measurements. As the sand grains are not spherical or even regular in shape, considerable care is required to ascertain the true mean diameter. The most accurate method is to measure the long diameter and the middle diameter at right angles to it, as seen by a microscope. The short diameter is obtained by a micrometer screw, focusing first upon the glass upon which the particle rests and then upon the highest point to be found. The mean diameter is then the cube root of the product of the three observed diameters. The middle diameter is usually about equal to the mean diameter, and can generally be used for it, avoiding the troublesome measurement of the short diameters.

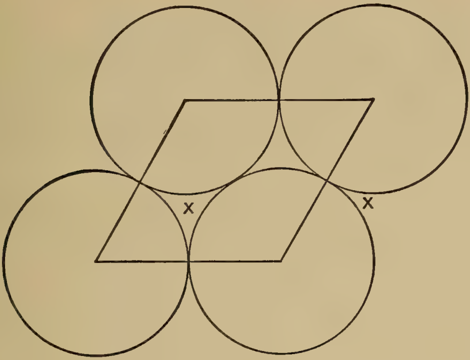
"The sizes of the separations of the sieves are always determined from the very last sand which passes through in the course of an analysis, and the results so obtained are quite accurate."

Voids in Sand.—Sand consists of particles of such shapes that they cannot be packed in any space without leaving intervals between the grains which are not filled. These spaces are known as voids and their volume and the size of the spaces are very important in characterizing different sands. The amount of volume of the voids and their size are dependent on the shape and variety in the size of the grains, upon the way they are arranged, and upon the degree to which they are compacted. If the sand grains were perfect spheres it can be regularly calculated what the percentage of voids in any volume will be. Dr. G. F. Becker, of the United States Geological Survey, has made this calculation for me and states the results as follows:

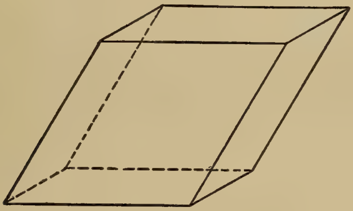
"Suppose, first, that 8 spheres of radius r are so arranged that the centre of each is at one corner of a cube and that the edge of the cube is $2r$. Then one-eighth of each sphere will be included within the cube, and the total of the spherical matter in the cube will be just one sphere. In this case the voids will be

$$\frac{2(r)^3-\frac{4}{3}\pi r^3}{(2r)^3}=1-\frac{\pi}{6}=0.4764.$$

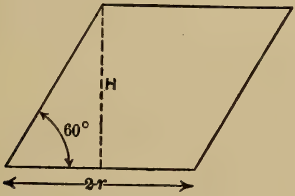
"Now shift the four spheres forming the lower layer into this order



which amounts to changing the angles made by the edges of the cube without any change in length. Also bring the centres of the upper layer of spheres over the point marked "x". Then the cube is distorted into an oblique prism of which this is a plan.



"It still includes just one sphere. The area of the lower surface of the prism will be



$$2rh = 2r.2r \sin 60^\circ$$
$$= 2r^2\sqrt{3}$$

and the height of the prism is the height of a tetrahedron formed by the centres of four spheres when three are placed in contact in one plane and the fourth is laid upon them. This height, and thus the whole volume of the prism, is

$$2r^2\sqrt{3}.r\sqrt{\frac{8}{3}} = 4\sqrt{2}r^3$$

and the interstitial space is

$$\frac{4\sqrt{2}r^3 - \frac{4}{3}\pi r^3}{4\sqrt{2}\,r^3} = 1 - \frac{\pi}{3\sqrt{2}} = 0.2595$$

"By diminishing all lines in one direction in the same proportion the system of spheres becomes a system of ellipsoids. Since the spheres and the interstitial spaces are distorted in the same manner, it is evident that a system of equal and similarly oriented ellipsoids may also be packed so as to leave only 25.95 per cent of voids. But if any ellipsoid is differently oriented from the rest, the voids will be greater."

With the spheres or regularly oriented ellipsoids packed as closely as possible the voids should therefore be 25.95 per cent, but it is not possible to pack small grains like sand in this regular way. They are jumbled together irregularly, and experiment has shown that perfect spheres like small bird shot when shaken and tamped until they are as compact as it is practical to make them with the devices at our command still contain voids of 32 per cent, or 6 per cent more than theory.

With spheres of quartz of similar size it would probably be impossible to compact them to the same extent, while if the material is merely poured loosely into the space which is to be filled and no attempt is made to attain greater compaction the voids will be found to be very much larger.

It is important therefore before going further to consider the conditions under which determinations of voids are usually made and to decide upon a uniform method, one which is the best to use in obtaining results of both absolute and relative value. There are several difficulties to be met with in arriving at the ultimate practical compaction of sand aside from the impossibility of bringing small particles of any size and shape into the closest possible juxtaposition.

Determination of the Voids in Sand.—The usual method of determining voids in sand, gravel, stone, etc., is to fill a vessel of known volume with the material in the condition under which it is desired to find the voids and then to pour in water until the space between the grains is filled, thus determining the voids from the relation of the volume of water to the volume occupied by the material examined. This method is satisfactory with coarse substances like gravel, but not when grains smaller than those which will pass a 30-mesh sieve are present. One reason why it is not satisfactory with fine material is because air is liable to be entangled between the grains and not to be replaced by water. According to another method a definite volume of the compacted material is poured into a measured volume of water. The increase in volume is that of the material and the difference is that of the voids. This is a more satisfactory way if no fine material or dust is present, which has a tendency to float in water or to obscure the meniscus.

It is better, therefore, to determine the specific gravity of the material of which the grains are composed and then calculate the voids from the weight of a definite volume of sand. For instance, if 100 cubic centimeters of quartz sand weighs 168 grammes and the specific gravity of the grains is 2.65 the voids may be found by dividing the weight by the gravity multiplied by 100 and subtracting the results from 100, the result in this case being $100-168\div2.65=36.6$ which is the per cent of voids by volume in this sand.

Where the ultimate practical compaction of fine material is sought, some further precautions must be taken, as this cannot be accomplished at all at ordinary room temperatures, as a film of adsorbed aqueous vapor adheres to each grain, which keeps them apart. With dust or 200-mesh material alone, air also is often imprisoned in the mass and increases the voids. If, however, the sand or dust is heated above the temperature of boiling water these difficulties are removed and the fine grains compact as well as coarser ones. As examples, the voids found in a sand and in a ground limestone when determined with hot and cold materials respectively were:

VOLUME OF VOIDS.

	Cold.	Hot.
Sand.........	34.2	33.3
Dust.........	56.6	38.0

In each determination the means employed for compaction were the same, but only when the material was hot was this complete, especially with the fine dust. The degree of compaction to which a substance such as sand is subjected of course influences the extent of the voids. The relation between those in a mass loosely poured into a cylinder and slightly shaken down but not compacted and those in a thoroughly compacted mass can be seen from the following determinations:

VOIDS.

	Loosely Compacted.	Thoroughly Compacted.
Long Island sand—coarse................	41.7	33.7
Buffalo—fine..........................	45.4	37.9
Chicago................................	42.2	35.5
New Orleans—very coarse................	37.6	29.6
Kansas City—very fine.	46.9	36.0

The voids in sands and mineral aggregates should of course be determined in a state of thorough compaction, as this is the condition in which these materials are or should be found in a finished asphalt surface.

Weight per Cubic Foot.—The voids being known in any sand or aggregate, and the gravity of the particles (for all practical purposes for quartz sand this may be taken as 2.65), the weight per cubic foot is calculated and is usually stated together with per cent of voids, as it is a factor of some importance in considering the relations of bitumen to the aggregate in certain surface mixtures, sand being frequently taken by volume—9 cubic feet—and as an indication of possible density of the finished surface.

The very considerable variations in the voids and weight per cubic foot in various unmixed sands examined in 1894 and later are seen in the following tables, pages 77 and 78.

VOLUME WEIGHTS AND VOIDS IN SANDS.

	Wt. per Cu. Ft. Loose.	Voids.	Wt. per Cu. Ft. Compact.	Voids.
Ballast—very fine	92.0	45.4	102.7	37.9
Buffalo—No. 3	97.1	41.2	110.4	33.2
New Orleans—Prophet Island—coarse	103.4	37.6	116.4	29.6
“ “ “ “ screened	100.9	39.1	113.6	33.3
“ “ —lakeshore	95.1	42.5	109.1	34.0
“ “ —Jordan River—much loam	82.4	51.2	95.3	42.4
Omaha	98.6	40.4	109.1	34.1
London—coarse	94.9	42.6	107.8	34.8
“ —fine	86.6	44.9	99.9	39.6
Yonkers—coarse	94.6	42.8	106.6	35.6
“ —fine	92.9	43.8	106.5	35.6
Chicago	95.6	42.2	107.7	35.0
Boston	94.0	43.3	106.4	35.7
New York	94.4	43.0	108.3	34.6
Kansas City—fine	87.0	46.9	105.9	36.0
“ “ —coarse	101.7	38.5	112.9	31.7
Altoona	92.4	44.1	105.1	37.7
Youngstown	92.4	44.1	105.0	36.5
Niagara Falls—No. 1	92.1	44.3	107.6	35.0
“ “ — “ 2	89.4	46.0	99.8	40.0
Louisville	91.9	44.5	101.6	38.6
Fort Wayne	91.4	44.7	108.8	34.3
Washington	89.2	46.1	100.1	39.5
Harrisburg—(much coal)	83.4	——	97.0	41.3

Voids as Affected by Size and Shape of Particles and by their Uniformity.—With the method of determining the voids in sands in a uniform and satisfactory way in mind, the peculiarities found in the aggregation of particles of mineral matter of different shape and size may be considered.

Voids in Sand Consisting of Particles of Uniform Size.—If the particles of a sand are all of uniform size, or nearly so, the voids present under our normal conditions will depend upon the shape of the particles alone. Sand the grains of which are perfect spheres would have, as has been noted for fine shot, voids of 32 per cent, theory being 25.95, whereas irregular fragments, such as are found in crushed stone, the crushed quartz of the sand-paper manufacturer, contain practically about 44 per cent, but if the particles are uniform their absolute size has no influence on the volume of the voids they show. As examples, the following

GRADING, POUNDS PER CUBIC FOOT, AND VOIDS IN VARIOUS SANDS OF 1899.

Test No.	Source.	Passing Mesh.								Total.	Retained on 10.	Lbs. per Cu. Ft.	Voids.
		200	100	80	50	40	30	20	10				
22693	Paterson, Sand Hill No. 16	3	9	6	36	23	13	5	5	=100%	....	104.7	36.6
22694	Paterson, Sand Hill No. 17	4	12	14	42	18	8	2	0	=100%	....	102.2	38.1
22768	Scranton, Tempering No. 1	3	15	23	56	3	0	0	0	=100%	....	104.7	36.6
22769	Scranton, Tempering No. 2	2	3	3	19	28	18	18	9	=100%	....	97.7	39.6
22789	Louisville No. 1, coarse	0	2	3	53	31	6	3	2	=100%	....	99.7	39.6
22790	Louisville No. 1, fine	23	24	16	28	8	1	0	0	=100%	....	103.4	37.4
22802	Saginaw, fine bank	17	50	18	13	2	0	0	0	=100%	....	102.2	36.1
22803	" Sag. River	2	5	7	47	26	8	3	2	=100%	....	107.2	35.1
22827	La Fayette No. 9, Wagner bank	6	20	12	50	10	2	0	0	=100%	....	107.2	35.1
22917	Kansas City, Kaw River, coarse	2	2	2	7	18	20	30	19	=100%	10%	112.1	32.1
22925	Washington No. 3, crusher dust	22	15	9	12	8	6	8	20	=100%	5%	105.9	35.8
22967	Chicago, fine sand	3	51	28	16	2	0	0	0	=100%	....	99.7	39.6
22968	" coarse sand	2	13	17	43	13	5	4	3	=100%	....	104.7	36.6

determinations of voids in crushed quartz of uniform but very varied size will sieve:

Crushed Quartz—very Sharp.	Volume Per Cent of Voids.
Passing 6-mesh sieve—not passing 10. . .	43.3
" 20- " " — " " 30. . .	43.4
" 90- " " — " " 100. . .	44.2

These materials represent a very coarse sand, a sand of size in use in concrete, and a very fine sand but all of the particles of very uniform size. They all contain, when compacted hot, the same volume of voids. Without compaction material of this description will, however, vary in proportion to the fineness of the particles; a coarse broken stone of uniform size will have 47 per cent of voids, while a similar fine sand will often have over 50, owing to the fact that the finer material will not naturally assume the same degree of compaction as the coarser material.

The crushed quartz, the voids in which, when compacted, have just been given, consists of extremely sharp particles with the angles of the original fracture unworn. In sands the grains are more or less round as has been shown, and in consequence they pack more readily and closely. If sands are taken and separated into portions the particles of each one of which are of nearly the same size—that is to say, will pass a certain sieve but be retained on one of the next smaller size—and the voids are determined for each of these, it will be found that there is a very considerable variation in the voids for the same sized particles of different sands and also for the different sizes, and that with all of them the voids are smaller in volume than was the case with the sharp particles of crushed quartz. Following are illustrations:

SIFTING.

Source.	Passing Mesh.								Total.
	200	100	80	50	40	30	20	10	
Buffalo—Canada lakeshore	17	24	15	24	10	4	4	2	=100%
Omaha—Platte River, 1897	5	13	34	31	8	3	4	2	=100%
Chicago—fine lake, 1897. . .	2	74	23	1	....	....	....	....	=100%
Detroit—fine lake, 1897. . . .	2	10	23	59	4	2	....	....	=100%
Kansas City—fine river, 1897.	10	15	23	44	6	1	1	....	=100%
Long Island bank, 1897. . . .	10	12	8	27	15	12	7	9	=100%
Buffalo—Attica fine bank. .	32	29	17	19	1	1	1	....	=100%

See also tables on pages 81 and 82.

The crushed quartz of about the 100-mesh size contains 44.2 per cent of voids. The 100-mesh particles of the fine Attica sand showed but 42.9 per cent and the same sized grains of the other sands much less, until those from the coarse Buffalo supply contained but 34.5 per cent.

Voids in Sand of Varying Sized Particles or Grains.—When the grains in a sand vary in size the voids are at once reduced in volume by the fitting of the smaller particles into the spaces between the larger ones, the voids at the same time becoming smaller in size as well as in volume.

VOIDS.

Source.	Loose—Hot.				
	Entire.	Passing Mesh.			
		200	100	80	50
Buffalo—Canada lake[1]	40.3%	....	41.8%	38.3%	42.0%
Omaha—Platte River, 1897	35.8	48.6%	43.7	42.6	42.9
Chicago—fine lake, 1897	46.3	....	43.6	46.6	46.8
Detroit—fine lake, 1897	41.1	....	45.8	44.0	41.3
Kansas City—fine river, 1897	41.0	49.8	45.9	44.6	42.9
Long Island—bank, 1897	39.2	50.1	49.0	48.1	47.3
Buffalo—Attica, fine bank, 1897	....	48.0	45.7	47.5	47.1

Source.	Tamped—Hot.				
	Entire.	Passing Mesh.			
		200	100	80	50
Buffalo—Canada lake[1]	34.6%	....	34.5%	32.8%	36.5%
Omaha—Platte River, 1897	33.5	44.5%	38.4	37.5	37.5
Chicago—fine lake, 1897	39.2	....	38.4	40.2	42.3
Detroit—fine lake, 1897	35.4	....	39.6	39.1	37.5
Kansas City—fine river, 1897	35.3	42.7	40.2	40.1	38.8
Long Island—bank, 1897	33.0	42.1	41.8	43.4	42.4
Buffalo—Attica, fine bank, 1897	32.0	37.7	42.9	41.3	41.4

[1] 1.33 per cent magnetite.

When the various sized particles, the voids in which taken separately are shown in the preceding table, are combined in the proportions found in nature, the voids are then, with one or two exceptions, much reduced. This is conspicuous in the Attica sand, which as a whole shows 32 per cent of voids, where its 200 mesh has 37.7 per cent and the coarser particles over 40 per cent.

The greatest reduction will of course occur where there are enough fine particles present of a size small enough to fit between the larger ones—for instance, dust with sand, sand with gravel, and gravel with broken stone. It was found that by adding dust

VOLUME WEIGHT OF HOT SAND, POUNDS PER CUBIC FOOT.

Source.	Loose—Hot.				Tamped—Hot.			
	Entire	Passing Mesh.			Entire	Passing Mesh.		
		100	80	50		100	80	50
Buffalo—Canada lake[1]	98.5	96.0	101.8	95.6	108.0	108.2	110.9	104.8
Omaha—Platte River, 1897	.....	92.9	94.6	94.2	109.7	101.6	103.1	103.1
Chicago—fine lake, 1897	93.5	93.1	88.1	87.8	100.3	101.6	96.7	95.3
Detroit—fine lake, 1897	97.2	89.5	92.5	96.9	106.6	99.7	100.6	103.2
Kansas City—fine river, 1897	97.4	89.3	91.5	94.3	106.8	98.7	99.1	101.1
Long Island—bank, 1897	100.3	84.2	85.5	87.0	110.8	96.1	94.0	96.1
Buffalo—Attica, fine bank, 1897	99.4	89.6	86.7	87.3	112.2	94.2	96.9	96.8

[1] 1.33 per cent magnetite.

in continually increasing portions to a sand with 35.5 per cent of voids, the percentage of voids in the mixture was gradually reduced to a certain point corresponding to the voids to be filled, but on further addition they were again increased, as shown by the following figures. This point was reached when the dust amounted to 41 per cent of the sand, an amount greater than the voids; but this is due to the fact that the sand grains were unavoidably separated to a very considerable extent by the dust and the voids consequently increased.

WEIGHTS AND VOIDS IN NEW YORK SAND WITH VARIOUS PERCENTAGES OF 200-MESH DUST.

	Weight per Cubic Foot.	Voids.
Original sand, compacted hot	106.0	35.5
12.4% of dust	114.0	31.0
16.7 “ “ “	116.0	29.1
20.6 “ “ “	120.2	26.6
24.2 “ “ “	127.0	23.0
30.4 “ “ “	130.0	21.2
36.0 “ “ “	132.5	20.0
41.7 “ “ “	133.1	19.7
50.0 “ “ “	114.6	24.7

When the densest of these sand and dust mixtures is added to a gravel with voids of 35.1 per cent in amount sufficient to fill the voids in the latter they are further reduced to about 12.1 per cent, and the aggregate weighs 144.8 pounds per cubic foot as compared to 164.1 pounds for solid quartz.

WEIGHT PER CUBIC FOOT AND VOIDS IN CRUSHED FLINT, GRADED LIKE THE AVERAGE SAND IN SEVERAL CITIES, COMPARED WITH THE LOCAL SANDS OF THESE CITIES OF THE SAME GRADING, WITH NO 200-MESH MATERIAL, WITH 13 PER CENT OF 200-MESH FLINT AND 13 PER CENT OF 200-MESH DUST. SPECIFIC GRAVITY OF FLINT=2.65.

	Without 200-Mesh Material.		With 200 Flint.		With 200 Dust.	
	Wt. per Cu. Ft.	Voids.	Wt. per Cu. Ft.	Voids.	Wt. per Cu. Ft.	Voids.
New York—1898:						
Local	109.6	34.1	115.6	30.5	118.9	26.5
Flint	105.5	38.1	109.0	34.0	110.9	32.9
Chicago—1898:						
Local	109.1	34.6	113.9	32.3	120.4	27.9
Flint	103.4	37.4	104.9	36.4	107.4	34.9
St. Louis—1899:						
Local	111.9	31.7	116.1	29.1	122.2	25.4
Flint	103.6	37.1	108.3	34.4	111.8	32.3
Louisville—1899:						
Local	104.5	36.0	110.9	32.1	115.7	29.1
Flint	99.6	39.5	107.0	35.2	112.2	32.0
Kansas City—1898:						
Local	110.4	32.5	115.0	29.9	122.4	25.3
Flint	103.0	37.6	106.2	35.7	113.5	31.0
Omaha—1899:						
Local	113.3	30.9	118.6	27.6	124.5	24.0
Flint	105.3	36.2	106.6	34.2	113.5	31.2
Trenton—1898:						
Local	111.1	31.6	117.1	28.2	123.5	24.1
Flint	107.6	34.8	112.6	31.8	116.0	29.7
Paterson—1899:						
Local	110.6	32.6	115.6	29.6	121.0	26.3
Flint	104.3	36.8	109.4	33.7	112.4	31.9
Washington—1899:						
Local	106.1	36.5	114.5	31.4	119.0	28.1
Flint	109.0	34.0	113.5	31.8	118.1	26.5
Buffalo—1899:						
Local	109.6	33.9	115.9	30.1	120.5	27.3
Flint	100.1	39.4	103.9	37.1	108.6	34.2
Philadelphia—1899:						
Local	107.8	35.2	111.3	33.1	119.4	28.2
Flint	104.5	36.7	106.5	35.5	113.9	31.0

Sharp as Compared with Rounded Sand.—If particles of the crushed quartz of sizes corresponding to those found in natural sand are combined in the proportions found in the latter, and the voids in each determined, the results are a striking illustration of the difference in the degree to which compaction can be carried with sand made up of sharp and rounded particles. (See preceding table, page 83)

As in the case of the single-sized particles the sharp sands do not compact as well as those with rounded particles, and as the greatest possible compaction is desirable, it seems that a rounded sand is more suitable for the construction of asphalt pavements than a sharp one. Experience has shown that this is the case. The particles should, however, be rounded and not round, as in the latter case they would move too easily on one another and give the pavement a tendency to displacement under traffic. It will not do, however, to draw too general conclusions from a determination of voids in a sand alone. Small voids are desirable, but may at the same time occur in sands which are unsuitable for use in a surface mixture. For example, sands too coarse to permit of being employed may have a smaller volume of voids than a finer or more suitable sand.

	Passing Mesh.								Total.	Wt. per Cu. Ft.	Voids.
	200	100	80	50	40	30	20	10			
Trenton.....	0	11	14	25	14	12	13	11	=100%	111.1	31.6
Philadelphia.	0	22	18	30	14	7	5	4	=100%	107.8	35.2

Here the coarse sand has the smaller volume of voids, which is quite often the case, but the size of the voids is too large and the sand is consequently undesirable. It is therefore necessary to consider the grading of a sand as well as its voids in judging it.

Grading of Sands.—The proper grading for an asphalt mixture is seldom found in a single sand, but it can be arranged by mixing two or more containing particles of different sizes. The character of the sands which have been used in mixtures in various cities is illustrated by the following examples.

SAND GRADING—VARIOUS CITIES.

Cities.	Passing Mesh.								Total.
	200	100	80	50	40	30	20	10	
Chicago—fine, 1896	10	68	15	5	2	...	...	...	=100%
" —medium	2	15	17	52	9	2	2	1	=100%
Louisville—river	2	1	4	53	25	10	3	2	=100%
" —bar	32	33	13	18	3	1	...	...	=100%
Milwaukee—coarse beach	0	1	2	36	32	17	9	3	=100%
" —White Fish Bay	2	25	29	36	4	3	1	...	=100%
Omaha—single sand, 1899	2	19	19	41	12	3	2	2	=100%
Shelby—single sand, 1899	2	14	26	49	6	2	1	...	=100%
Boston—single sand, 1899	6	13	14	31	20	10	4	2	=100%
St. Louis—coarse, 1897	0	1	1	48	46	3	1	0	=100%
" —fine, 1897	14	26	14	38	6	2	...	...	=100%
" —river, coarse	2	4	22	28	19	10	10	5	=100%
" — " fine	17	40	30	10	1	1	1	...	=100%
Buffalo—bank, fine	31	39	21	8	1	...	...	...	=100%
" —lake, fine	2	9	36	49	3	1	...	...	=100%
" — " coarse	1	6	10	41	19	15	5	3	=100%

The preceding data show the very great variations in the character of different sands, not only as to the size and shape of the grains, which are of the utmost importance in preparing a surface mixture, but also in the character of the surface of the grains. It does not seem too much to say, therefore, that the selection of a suitable sand or the combination of two or more in a proper way is as important a detail in producing a satisfactory asphalt pavement as the regulating of any of the other constituents. The difficulties to be met with are numerous and demand experience in meeting them.

Stone.—Stone is sometimes used as a part of the mineral aggregate, and this use has grown of late years. When it forms the chief portion of the wearing surface the latter is known as an asphaltic concrete. This material will be considered in a later part of this volume.[1]

SUMMARY.

In this chapter the very varied character of the sand which is the chief constituent of the mineral aggregate of an asphalt surface mixture has been shown, and that skill is necessary in selecting this material for the preparation of a satisfactory mixture. Sands differ according to their origin and the source from which they are obtained. They differ as regards the size of the grains of which they are made up, the relative proportion of different sized grains which are present, the shape of the grains, the character of the surface and of the material of which they are composed, and the proportion of the voids or vacant spaces between the grains when compacted. They also vary in their volume weight, a matter of importance where materials are mixed by weight and not by volume.

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[1] Page 375.

Altogether there seems to be nothing more important for the construction of a satisfactory asphalt surface mixture than a thorough understanding of the peculiarities of the various sands and of their adaptability to the purpose for which they are used.

CHAPTER IV.

FILLER, OR DUST.

A FILLER, or dust, is made a part of the mineral aggregate of asphalt surfaces for the purpose of rendering the surface more dense, so that it will be less acted upon by water, and less liable to interior displacement or movement. Its presence in a surface mixture may be looked at in much the same way as that of the finer clay particles in a soil. In fact soil physics, as treated by the agricultural physicists, is in many directions instructive as applied to surface mixtures, which are aggregates of small particles like soils and contain more or less bitumen as the soils do more or less water.

In regard to the different parts played by fine and coarse particles in a soil, Whitney remarks:[1]

"In a symmetrical arrangement of the grains in a soil containing 47.64 per cent[2] by volume of empty space, each grain will touch the surface of six adjacent grains. There is a certain amount of surface attraction between these particles.

"If the grains are large they still only touch at six points, and the weight of the grains is sufficient to overcome this slight surface attraction. A lump of wet sand will fall apart as it dries, for it is bound together by the contracting power of the film of water which surrounds it, and when this is removed by evaporation the weight of the grains is sufficient to overcome the surface attraction of the relatively large and heavy particles and they fall apart.

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[1] Bulletin No. 4, U. S. Weather Bureau, 1892, 27.

[2] Whitney is, of course, wrong in assuming this volume; the voids, as has been shown on page 74, might be 25.95 per cent.

"If the grains are very small, like grains of clay, the surface attraction of the grains is sufficient to bind the mass into a compact lump when dry; for while there are still only six points of contact for any one grain, there are many other grains and so many more points of contact in a given weight of material. If the size of the grains was still further reduced to molecular proportions the mass would assume the hardness and rigidity of a single grain of sand or clay."

These facts apply as well to asphalt-surface mixtures as to soils, and explain the parts which a filler plays.

This, however, has been little understood heretofore in the paving industry.

Dust in the Earlier Days.—In the earlier days of the industry, and even as late as 1885, the Washington specifications for asphalt pavements read that the mixture shall contain 12 to 15 per cent of carbonate of lime and that "the powdered carbonate of lime will be of such a degree of fineness that 16 per cent by weight of the entire mixture for the pavement shall be an impalpable powder of limestone and the whole of it shall pass a No. 26 screen. The sand will be of such size that none of it will pass a No. 80 screen and the whole shall pass a No. 20 screen." As a matter of fact, very little real dust, 200 mesh, was put in the mixture and it was a question even as late as 1893 whether dust contributed in any way to improve it.

That it is of the greatest value, especially in surface exposed to heavy traffic, is now known. The difference in the penetration, ductility, and resistance to stress of the same bitumen with and without filler can be readily shown.[1] Filler, therefore, enables us to use a softer cement than otherwise would be the case and thus make an asphalt surface less liable to mark in hot, less brittle in cold weather, and far less liable to internal displacement. In the earlier asphalt pavements where Trinidad asphalt was the only cementing material in use this contained in itself so much fine inorganic matter which was a natural filler that it was a great help to the surface before the necessity for the presence of a high percentage of dust was understood.

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[1] See page 373

The use of a filler is well illustrated in the laying of coal-tar walks in England, where very soft coal-tar is mixed with all the slaked lime it will hold, often more than 50 per cent by weight, and this mixture used as a cement with sand. The filler makes it possible to use a tar so soft that it will not crack in winter, while preventing its marking excessively in summer.

Varieties of Filler.—Numerous kinds of mineral matter, ground to a more or less fine powder, have been used from time to time in asphalt mixtures as a filler. These include

Limestone,
Hydraulic limestone,
Trap rock,
Volcanic,
Marl,
Silica,
Caustic or slaked lime,
Natural hydraulic cement,
Portland hydraulic cement,
Clay,
Ground shale,
Dust-collector dust,
Ground waste lime from beet-sugar factories.

Ground Limestone has been used far more than any other and was the original material employed by De Smedt. There is probably nothing better than this, unless it be Portland cement, for heavy-traffic streets. It is a desirable material, as asphalt cement adheres to it firmly and does so by being absorbed by it to a certain extent.

Ground hydraulic limestone has also been used where it could be conveniently and cheaply obtained from the cement manufacturers. It is, no doubt, as suitable for its purpose as the simple carbonate.

Ground Shale.—In the manufacture of shale bricks the shale is first ground to a powder which is often extremely fine and in consequence suitable for use as a filler. Such a shale dust is available in the State of Washington, 91 per cent passing a 200-mesh screen and 79 per cent remaining suspended in water for fifteen seconds.

Ground Clay or loam free from organic matter could also be used in a similar way. A large part of the natural filler in Trinidad asphalt is clay, and on this account it was thought that clay might eventually prove the most desirable filler, as owing to its peculiar surface and porosity it will absorb bitumen much more satisfactorily than any of the ground rock fillers, but it has been found to have such a small volume weight and to be so light and fluffy that a large part of the clay is blown away in an open mixer and it can only be used successfully in a tightly-closed one, which is rarely available. In this connection the studies of Dr. A. S. Cushman, of the Office of Public Roads, U. S. Department of Agriculture, on "The Nature of Clay" and on "The Adsorption of Solids by Rock Powders" are of great interest.

Ground Waste Lime from Beet-sugar Factories.—In the process of defecating the diffusion liquors obtained in the extraction of sugar from beets large quantities of caustic lime in the form of cream of lime are used, which is subsequently removed from the sugar solution by filtration. This when dried and ground has been suggested for use as a filler and employed to a small extent in California and Michigan. As far as fineness is concerned it is a satisfactory material, but it contains many impurities such as organic matter in the form of sugar and organic acids combined with lime. Analysis shows that it has the following composition:

COMPOSITION OF DRIED AND POWDERED BEET-SUGAR FILTER-PRESS CAKE.

Calcium carbonate	78.0%
Free lime	1.0
Lime combined with organic matter	5.0
Magnesia carbonate	2.0
Alkalies	.2
Iron and alumina	2.6
Sulphuric, phosphoric, and oxalic acids	2.4
Sugar	5.0
Organic not sugar	2.1
	98.3

It is to a certain extent an open question whether the organic matter will prove deleterious to the surface mixture and the free lime likewise. Experience alone can prove the availability of this material as a filler.

Ground Marl has served of late years as a filler in those cities near the marl-beds of Ohio and Michigan. It gave fairly satisfactory results, but its disadvantage lies in its low volume weight, in consequence of which it is readily blown away on mixing it with sand, and its use has been discontinued.

Ground Silica.—Ground sand and trap-rock have been largely used in the work in New York. It is questionable if it is desirable as a substitute for limestone, as asphalt does not adhere to it as well and it cannot be ground as fine. It is a filler, however, and successful results have been obtained with it.

As between ground limestone and silica or silicate dusts, experiments of Mr. F. P. Smith, formerly of the Alcatraz Asphalt Co., have shown that the former enables a mixture made with it to resist water action better than the silica filler, and this can be readily understood for the reason that has been given, namely, that bitumen will adhere to the former much more firmly than to the latter by being partly absorbed by it.

Caustic and Slaked Lime.—These fillers have only been used experimentally. They are largely employed in coal-tar work. No peculiarities have been noticed in the small amount of work done with them, but in the laboratory cylinders of surface mixture containing caustic lime expanded badly on immersion in water. It would probably not be desirable to experiment further with their use.

Natural Hydraulic Cement.—This material began to be used as a filler in cases where limestone dust was not available. However, of late years its use has been abandoned, as it has been observed that surfaces laid with this material as a filler have cracked more than where limestone was the ground material. It seems to possess the property, perhaps owing to the presence of free lime, of hardening the asphalt cement very rapidly. If it is necessary to use such a filler the cement should be at least 20 points softer than would be the case with other materials.

Portland Cement.—This is a material which, for some reason not yet satisfactorily explained, gives the best results as a filler in asphalt surfaces, especially on streets of heavy traffic or where the surface is subject to the action of water. Its desirability may be due to its capacity for adsorbing a thick film of bitumen, but it cannot with certainty be attributed to its hydraulic properties.

A cylinder of open Trinidad asphalt surface mixture, made up in Washington, D. C., in 1894, half of which contained limestone dust as a filler and the other Portland cement, showed the most striking contrast in its appearance after nearly six years' immersion in water, the portion containing Portland cement being still hard and firm, while the ordinary limestone mixture was much more strongly acted upon.

The slight extra cost of Portland cement is more than made up by the improvement in the character of the surface, where especially trying conditions are to be met, and its use is highly to be commended.

Fine Grinding of the Filler.—The material which is of value in a filler is the impalpable dust, much finer than the particles merely passing a 200-mesh sieve. Sandy particles of dust of about the 200-mesh size are probably of somewhat greater value than the 200-mesh rounded particles of an ordinary sand, which are at times distinctly disadvantageous in a mixture, as they are sharper. Larger particles do not differ from sand grains of the same size.

It is important, therefore, in securing a filler that it should contain as much real dust as possible. If there is only 45 per cent of this material, twice as much must be used as if it contained 90 per cent. In the former case the sand must be heated to a much higher temperature to take care of so much cold material, while in the other, as a matter of economy, the smaller bulk to be handled to accomplish the same object is an important consideration.

As it is difficult to find a desirable filler on the market, dust should be ground by paving companies themselves. It can be turned out with a tube-mill 85 to 95 per cent fine. There is no question but that the production and use of such dust will pay if for no other reason than to do away with the excessive cooling of the mixture caused by the addition of the large quantities of cold, coarse material to the sand which are necessary to obtain a sufficient amount of true filler.

More Refined Methods of Examining Filler.—Up to the present point fillers have chiefly been spoken of, as to their fineness, according to the amount which will pass a 200-mesh sieve, the finest wire sieve that is made. As has been said, the material passing this sieve may be much of it sand smaller than .10 mm. in diameter, and very little of it may be true dust or filler of a diameter smaller than .025. The difference in character of the two sizes is readily seen on inspection.

In judging the value of a filler it is desirable to determine the relative amount of these materials, coarse material, and the impalpable dust. As there are no finer sieves than the 200-mesh, this can only be done by elutriation, or washing with water, the coarser grains settling out rapidly and the finer more slowly. The manner of doing this is as follows:

Five grams of the dust to be examined are placed in a beaker about 120 mm. high, holding about 600 c.c. The beaker is nearly filled with distilled water, at a temperature of exactly 68° F., and agitated with an air-blast until the dust and water are thoroughly mixed, taking care not to produce cyclonic currents in the latter. On stopping the blast the liquid is allowed to stand exactly 15 seconds and the water above the sediment immediately decanted without pouring off any of the latter. This washing is repeated three times. The sediment is then washed out into a dish, dried, and weighed. The loss in weight represents that portion which may be considered as dust free from sand. The washing must be done with distilled water and at a definite temperature.

This method can also be used with hydraulic cements or materials acted upon by water, since the finer portion is the only part acted upon, while the coarser part, which is recovered and weighed, is not acted upon at all.

The differentiation of the particles not subsiding in 15 seconds can be carried further, if desired, by reagitating the decanted liquid and allowing the sedimentation to go on for 1 minute, 30 minutes, 1 hour, and so on. For ordinary purposes this is unnecessary.[1] The size of the particles obtained by elutriation can be measured in the same way as that of the particles passed by the finer sieves, as described by Hazen. The size of these particles among ordinary fillers will be found in the following table:

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[1] For further details, see Hazen, 24th Annual Report Massachusetts State Board of Health, 1892, 541.

VOLUME WEIGHT OF DUST.

Test number	75803	75804	75805	75806	71076	75791
Dust	Limestone	Trap rock	Port. cement	Clay	Marl	Volcanic
Passing 200-mesh	84.0%	81%	74%	93%	92%	100%
" 100- "	14.0	18	19	5	4	
" 80- "	2.0	1	6	1	2	
" 50- "	....	....	1	1	2	
Elutriation test not settled in 15 seconds	71.3%	70.3%	56.7%	87.8%	80.3%	98.2%
Pounds per cubic foot	113.7	112.3	123.5	78.0	78.0	63.4

A number of dusts from various parts of the country have been differentiated and the results are as follows:

SIZE OF PARTICLES IN VARIOUS FILLERS.

Test No.	Character.	Per Cent Passing 200.	Per Cent on 200.
30915	Limestone.	96	4
30963	Silica.	96	4
30267	Limestone.	91	9
30578	"	93	7
30715	"	48	52
30716	"	66	34
30766	Silica.	67	33
30606	Marl.	91	9

In these fillers, as supplied for use, there was present the percentages of particles passing a 200-mesh sieve shown in the preceding table.

This 200-mesh material consists of the following sized particles:

Time of Subsidation.	Average Size of Particles Less than	Test No.							
		30915	30963	30276	30578	30715	30716	30766	30606
Difference and loss........	.001 mm.	4.4	1.0	3.8	.4	2.7	11.9	3.2	2.4
16 hours......	.0025 "	2.8	4.2						
2 "	.0075 "	5.0	2.9	4.9	5.4	3.1	3.2	3.0	7.7
30 minutes. . .	.025 "	51.3	42.4	55.1	67.4	32.5	23.9	23.3	66.5
1 minute......	.050 "	17.7	9.3	15.0	12.9	24.8	20.1	25.6	13.0
15 seconds. ...	.080 "	18.8	40.2	21.2	13.9	36.9	40.9	44.9	10.4
		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Actual dust in original material smaller than.....	.050 "	78.0	55.6	71.7	80.1	30.3	39.0	36.9	80.5

As showing the variation in the amount of material which is not ground even fine enough to pass a 200-mesh sieve the first data given may be examined. The coarse material varies from 4 per cent in high-grade fillers to 52 per cent in an inferior article. Separating out and rejecting this coarse material as of no value greater than that of sand the finer grains were separated by elutriation into the particles of the sizes given.

It seems fair to consider that particles smaller than .050 mm. in average diameter are the only portions of a filler to be considered as true dust, and it will be seen that of the entire material in several instances only 30–40 per cent is dust and the remainder sand.

A good filler should contain at least 60 per cent of its weight of actual dust and preferably over 70 per cent.

An examination of a filler or even a mixture in this way is very serviceable in revealing the actual amount of fine dust which either may contain. In a mixture examined in New York the actual amount of dust of different sizes is shown in the following analysis:

TEST NO. 30954.

	Settling in, Time.	Size of Particles Less than			200 Mesh on 100 Per Cent Basis.
Bitumen				11.0%	
Passing 200	Difference, or loss		.8%		4.2%
" "	2 hours	.0075 mm.	.3		1.6
" "	30 minutes	.025 "	2.5		13.8
" "	1 minute	.050 "	4.2		23.8
" "	15 seconds	.080 "	10.2	18.0	56.6
					100.0
" 100				14.0	
" 80				15.0	
" 50				25.0	
" 40				10.0	
" 30				2.0	
" 20				3.0	
" 10				2.0	
				100.0	

Sand	77.6%
Dust	5.4
Trinidad A. C.	17.0
	100.0

The dust was the finest-ground limestone of the composition given in the preceding table. It contained, as used, 81.2 per cent of particles not subsiding in 15 seconds. From the amount of dust in use it is readily calculated that no more than 4.3 per cent of material which acts as a filler would be expected in the mixture. 7.9 per cent is actually found, the excess over the calculated 4.3 per cent being due to the fine material derived from that in the Trinidad asphalt. The small percentage of real dust in some of our mixtures is therefore striking.

SUMMARY.

The character of the filler or finely ground inorganic matter which enters into the composition of the mineral aggregate of an asphalt surface has been shown in the preceding chapter to be a matter of very considerable importance. Impalpably fine mineral matter of various kinds can be satisfactorily used, but it should be as fine as possible, and for construction of an asphalt pavement on streets of heavy travel Portland cement should alone be used as a source of supply.

The intelligent use of filler in an asphalt surface mixture demands further careful consideration from a physical point of view, and the investigations which have been carried on in regard to rock powders in the Office of Public Roads, U. S. Department of Agriculture, have thrown much light upon this subject.

CHAPTER V.

THE NATURE OF THE HYDROCARBONS WHICH CONSTITUTE THE NATIVE BITUMENS.

Asphalt cement is the distinctive feature of an asphalt pavement. It serves to bind the mineral aggregate together and enables it to carry traffic without displacement.

It consists of some native asphalt or other hard native bitumen, fluxed with some soft bitumen in the form of dense petroleum oil or maltha, or of some hard residue from the distillation or treatment of asphaltic petroleum, softened to a proper consistency in the same way.

Asphalt cement is, therefore, native bitumen and its intelligent consideration necessitates a knowledge of and the differentiation of the various native bitumens of which it may be made up.

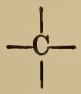
The hydrocarbons, or compounds of hydrogen and carbon, which when mixed in varying proportions constitute the substances which are known as bitumen, belong to different *series*, so called, which are characterized by the relative proportion of hydrogen and carbon atoms which they contain and by their structure or the relation of the carbon atoms to one another in space. A short explanation in regard to the structure of the various hydrocarbons of these series is necessary for an intelligent understanding of their properties as affecting the character of the bitumen in use in asphalt pavements.

Chain Hydrocarbons.—The carbon atom is characterized chemically as being quadrivalent; that is to say, it possesses four affinities, bonds, or links by means of which it may be said to combine with atoms of other elements. The hydrogen atom has but one bond and is univalent.

If a carbon atom combines with all the hydrogen atoms that it is capable of, its four bonds must each be linked with a hydrogen atom, and the resulting molecule will consist of one atom of carbon and four of hydrogen, which can be represented by the symbol CH_4, in which C stands for one carbon atom and H_4 for four hydrogen atoms. In this substance or compound, which is known as methane, or marsh-gas, we have the carbon atom saturated as to its affinities, or bonds, with hydrogen atoms. It cannot combine with any other atom except by replacing with it one or more of the hydrogen atoms. It is, therefore, known as a saturated hydrocarbon.

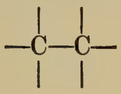
If two, three, or more atoms of carbon are combined in the same way to form a molecule having C_2 or C_3, etc., in its composition, these carbon atoms are themselves linked or bonded together by one or more of the bonds of each atom, so that we may have:

One carbon atom with its four affinities or bonds which may be represented thus:



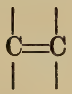
$$\begin{array}{ccc} & | & \\ - & \mathrm{C} & - \\ & | & \end{array}$$

Two carbon atoms joined by one affinity of each thus:



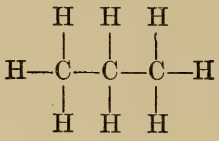
$$\begin{array}{ccccc} & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - \\ & | & & | & \end{array}$$

Or by two affinities of each thus:



$$\begin{array}{ccc} | & & | \\ \mathrm{C} & = & \mathrm{C} \\ | & & | \end{array}$$

In the case of two carbon atoms joined by one affinity each, there are six bonds remaining to unite with hydrogen. The resulting compound with hydrogen in this case is represented by the symbol or formula C_2H_6. It is a saturated hydrocarbon in the same way that CH_4, with one atom of carbon, is, because, while two bonds out of the eight of the two carbon atoms are necessarily joined in linking the carbon atoms together, all the remaining available affinities are satisfied by hydrogen. In the same way with three atoms of carbon in the molecule we have the carbon atoms linked to each other, so that eight affinities out of twelve remain to be saturated by hydrogen thus:



$$\begin{array}{ccccccc} & & H & & H & & H & \\ & & | & & | & & | & \\ H & — & C & — & C & — & C & — & H \\ & & | & & | & & | & \\ & & H & & H & & H & \end{array}$$

One atom is, of course, linked to two others, and so two affinities of this atom are not available for combining with hydrogen. This saturated hydrocarbon is represented by the symbol C_3H_8.

As the carbon atoms increase in number there is found to be a regular increase in those of hydrogen, so that the compounds of this saturated nature become what is called a homologous series, differing by one carbon and two hydrogen atoms from the following and preceding.

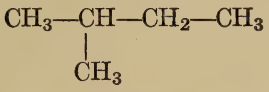
$$CH_4,\ C_2H_6,\ C_3H_8,\ C_nH_{2n+2}.$$

If in any of these simple chain hydrocarbons, which owing to the simplicity of their constitution are known as normal hydrocarbons, one of the hydrogen atoms is supposed to be removed, a group is left with one free affinity, or if two hydrogens or more are removed, with two or more affinities. These imaginary groups of atoms with different affinities are known as radicals. They can combine with other similar radicals or with other elements, such as the halogens, or with acid radicals. Thus we may have

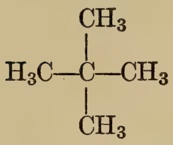
CH_4	$—CH_3$	$=CH_2$	$\equiv CH$
Saturated.	Methyl.	Methylene.	Methenyl.

If different hydrocarbon radicals are substituted for hydrogen in other hydrocarbons new hydrocarbons result. In this way hydrocarbons are produced which have the same composition or number of carbon and hydrogen atoms as in the normal hydrocarbon, but a different structure. For pentane, therefore, C_5H_{12}, there may be three forms:

$$CH_3—CH_2—CH_2—CH_2—CH_3$$



$$\begin{array}{l}CH_3—\overset{}{CH}—CH_2—CH_3\\ \qquad\;\;|\\ \qquad CH_3\end{array}$$



$$\begin{array}{c}CH_3\\ |\\ H_3C—C—CH_3\\ |\\ CH_3\end{array}$$

Here the straight chain is converted into one with one or more radicals known as side-chains.

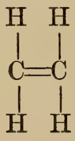
These hydrocarbons are denominated normal pentane, isopentane, and tetramethylmethane, the latter being methane in which the four hydrogen atoms are substituted by methyl groups. They are also known as isomers, since they contain the same number of carbon and hydrogen atoms; that is to say, have the same percentage composition but a different structure and different physical properties.

With similar hydrocarbons in which the carbon atoms are greater in number the possible variations in structural arrangement are much more numerous, and it can be readily seen that the number of different paraffine hydrocarbons is enormous.

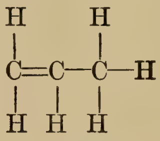
These compounds of carbon and hydrogen illustrate what is meant by a series of hydrocarbons, which is, in this case, a saturated series known as the paraffine, limit, or chain series, since the carbon atoms are represented as linked in the form of a chain. It is the series which makes up the greater part of ordinary Pennsylvania and Ohio petroleum and the residuum made from these oils.

In this series, the carbon being combined with as much hydrogen as possible, there is the largest percentage of hydrogen and the smallest percentage of carbon found in any hydrocarbons of a given number of carbon atoms. For marsh-gas, CH_4, it is 75 per cent carbon and 25 per cent hydrogen, a proportion gradually diminishing as the number of carbon atoms increases. For example, for $C_{30}H_{62}$ it is carbon 85.31, hydrogen 14.69.

Unsaturated Hydrocarbons.—When the carbon atoms in a hydrocarbon do not combine with all the hydrogen atoms they might, the remaining affinities are satisfied in joining the carbon atoms together, in addition to the single bond found in the saturated series. The linking of the carbon atoms is then doubled and the hydrocarbons may be represented thus:



$H_2C=CH_2$



$H_2C=CH-CH_3$

Owing to the double bond, two affinities which in the unsaturated series were combined with hydrogen, are now linked with each other and a new series is determined in which the hydrogen atoms number always twice the carbon atoms. The affinities of the carbon are not entirely satisfied with hydrogen, and the hydrocarbons are known as unsaturated hydrocarbons. As the relation of carbon to hydrogen is constant the percentage composition of all the hydrocarbons of the C_nH_{2n} series is carbon 85.71, hydrogen 14.29, the amount of hydrogen being always less than in any of the hydrocarbons of the saturated series containing the same number of carbon atoms.

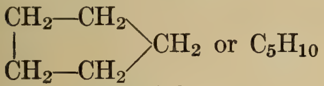
In this series, which is known as the Olefine Hydrocarbons, but two of the carbon affinities are joined by a double bond. More of these affinities may be joined in this way, resulting in other series represented by the general formula C_nH_{2n-2}, C_nH_{2n-4}, C_nH_{2n-6}, etc., in which the per cent of hydrogen is still less.

The hydrocarbons of these series, it is plain, are even more unsaturated.

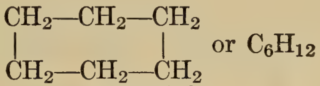
Hydrocarbons in general are divided, therefore, into those which are saturated and those which are unsaturated, the former being stable and the latter reactive and very susceptible to change, combining with or being converted into other hydrocarbons by the action of sulphuric acid and other reagents. The saturated can be separated from the unsaturated hydrocarbons by strong sulphuric acid, and this will be found to be a very important means of differentiating the oils and the solid bitumens among themselves, by determining the relative proportions of these two classes of hydrocarbons which they contain.

Cyclic Hydrocarbons.—In the preceding hydrocarbons the carbon atoms have been imagined as being linked in the form of a chain of more or less simplicity. It can readily be imagined that the normal chain can be bent into the form of a circle so that the carbon atoms at the ends may be united with each other by one of each of their three affinities. In this way a ring is formed, each carbon atom of which has only two affinities unsaturated, but which possesses no double bond when these affinities are all satisfied with hydrogen, so that although its general formula is C_nH_{2n}, the same as that of the unsaturated olefines, they are saturated hydrocarbons.

Owing to reasons which it is unnecessary to go into in this place the carbon atoms in such a ring do not exceed seven in number, as above that they would be quite unstable and could not exist. The most stable rings are those of five and six atoms, and hydrocarbons with this number are the foundation or source of many of the solid native bitumens. Their structure may be represented as follows:



Pentamethylene.

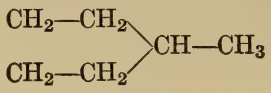


Hexamethylene.

The carbon-hydrogen groups of which they are made up are the groups or radicals known as methylene.

For this reason the hydrocarbons are known as a class as the polymethylenes, pentamethylene being the hydrocarbon of five groups, hexamethylene the one of six. The generic name of naphthenes is also applied to the series, having been used to designate the polymethylenes occurring in Russian petroleum before their structure was elucidated. They are distinguished by the fact that, although not as stable as the paraffine hydrocarbons, they still possess the stability of saturated compounds and are unacted upon by strong sulphuric acid.

In these polymethylenes, as in the normal chain hydrocarbons, one or more of the hydrogen atoms can be substituted by radicals like methyl. We have, for instance, methylpentamethylene, in which one of the hydrogen atoms of one of the methylene groups in pentamethylene is substituted by CH_3 the methyl group:



or

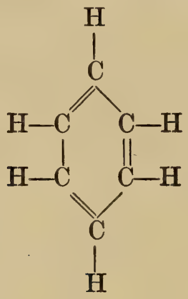
$$C_6H_{12}$$

It will be noted that this hydrocarbon has the same formula as hexamethylene and differs from it only in structure. They are isomers.

More complicated chains can exist, as where the radical propyl C_3H_7 or others replace the methyl radical and the possibilities in number and isomerism is again immense.

The more complicated single-ring polymethylenes with side-chains are more reactive than the simple naphthenes.

Unsaturated Cyclic Hydrocarbons.—Corresponding to these so-called cyclic saturated hydrocarbons, in which the carbon atoms are only united with each other by one bond, unsaturated cyclic hydrocarbons exist in which double bonds occur. The most familiar hydrocarbon of this type is benzol, derived from coal-tar, which has the following structure:

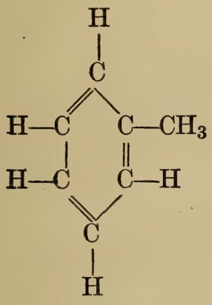


This forms a new series known as the benzol or aromatic series, the general formula for which is C_nH_{2n-6}.

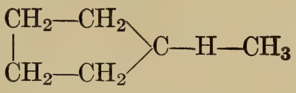
These hydrocarbons occur in a greater or less degree in all petroleums, at least among the more volatile portions, and are particularly prominent in California and Russian petroleum.

Where the number of double bonds is fewer than in the benzol ring other series of hydrocarbons are formed, known as the hydro-aromatic series, the hydrocarbons of which, in their constitution, are between the saturated polymethylenes and the aromatic compounds. The terpenes are members of this series, but they are not found in the solid native bitumens used in pavements. Hexahydrobenzol is the same thing as hexamethylene and is a saturated hydrocarbon. Tetrahydrobenzol is an unsaturated hydrocarbon corresponding in the cyclic series to the olefines of the chain hydrocarbons.

In all of these aromatic and hydrated aromatic hydrocarbons, as well as in the saturated polymethylenes, any or all of the hydrogen atoms may be substituted by paraffine or olefine radicals, thus making it possible to form a vast number of new hydrocarbons containing side-chains, of which toluol, or methyl benzol, is a type in the aromatic series, as was methyl pentamethylene in the polymethylene series.

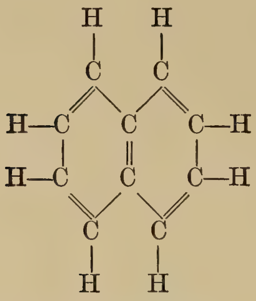


Methylbenzol.



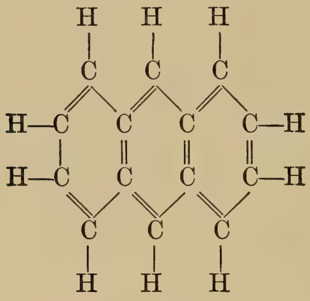
Methylpentamethylene.

Dicyclic Hydrocarbons.—The cyclic hydrocarbons thus far considered have consisted of but one ring. Dicyclic and polycyclic hydrocarbons are also known to exist in which two or more rings may be united by having carbon atoms in common, as in the case of naphthalene, $C_{10}H_8$, the result of the condensation of two benzol rings:



or $C_{10}H_8$

or of three rings, as in anthracene:



or $C_{14}H_{10}$

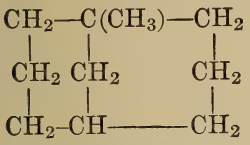
The latter substance may also be considered as consisting of two benzol rings united by two methenyl radicals.

The benzol rings may also be united by free affinities or by one or more methylene radicals without common carbon atoms, as in diphenyl, $C_6H_5—C_6H_5$, as dibenzyl, $C_6H_5—CH_2—CH_2—C_6H_5$, stilbene, $C_6H_5CH{=}CHC_6H_5$, or as tolane, $C_6H_5C{\equiv}C\ C_6H_5$.

These hydrocarbons are mentioned, not from their immediate interest in connection with the bitumens, as they only occur in coal-tar, but as showing the infinite variation in structure, which is possible.

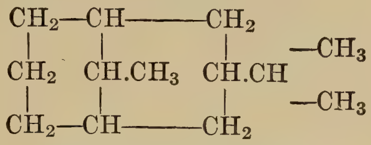
Polycyclic Polymethylenes.—In the polymethylene series bicyclic and polycyclic hydrocarbons also exist, in which two or more rings have common carbon atoms, but instead of two carbon atoms being common to both rings, as in naphthalene, three such are found in the bicyclic polymethylenes, forming what is known as a bridge structure. This is illustrated by two hydrocarbons prepared synthetically by Rabe and Weilinger[1] and having the following structure :

$C_{10}H_{18}$



Methyl-bicyclo-nonane.

$C_{13}H_{24}$



Isopropyl-methyl-bicyclo-nonane.

The latter hydrocarbon has probably been found by Coates in Louisiana and by Mabery in Santa Barbara, Cal., petroleum,[2] as can be seen from the close correspondence in the physical and other characteristics of the synthetic and native hydrocarbons.

	Synthetic.	Louisiana.		California.
Specific gravity	0.8646	0.8629		0.8621
Refractive index	1.460	1.4692		1.4687
Molecular refraction:				
Found for $C_{13}H_{24}$	57.677	57.93		58.05
Calculated	57.737	.....		.....
Boiling-point, 755 mm. ...	232	235		
28 mm. ...	132		60 mm.	150
Ultimate composition:				
Carbon	86.48–86.56	86.58		86.68
Hydrogen.............	13.28–13.15	13.42		13.62
Calculated:				
Carbon	86.67			
Hydrogen.............	13.33			

The hydrocarbons of the heavier asphaltic petroleums are, therefore, probably bicyclic or bridge compounds in those of lower boiling point, and polycyclic in the higher ones.

In the lightest oils from Trinidad asphalt a hydrocarbon has been isolated which has the same formula as the preceding ones, but differs from them in some of its characteristics, as can be seen from the data on the next page.

This hydrocarbon, while in some respects like those prepared by synthesis and from the California and Louisiana petroleums, is

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[1] Berichte der deutschen chemischen Gesellschaft, 1904, **37**, 1667–1675.

[2] Coates, J. Am. Chem. Soc., 1906, 384. Mabery, Proc. Am. Acad., 1904, **40**, 340.

HYDROCARBON FROM TRINIDAD ASPHALT.

Specific gravity	.8690
Refractive index	1.4721
Molecular refraction, found	57.98
" " calculated	57.737
Boiling-point, 30 mm.	170–180°
Ultimate composition:	
Carbon	86.85
Hydrogen	13.34

sharply differentiated from them by its much higher boiling point, and cannot, consequently, be of the same structure. The asphalt hydrocarbons differ, therefore, from those found in the petroleums, but apparently are of a similar nature, and the lowest ones at least of the series, are probably substituted bicyclic or bridge polymethylenes, the higher being polycyclic. The idea previously advanced by Markownikoff, Mabery and the author that they were probably two rings united by polymethylene groups, is seen to be untenable.

Hydrocarbon Derivatives.—Hitherto hydrocarbons only have been described as constituents of the native bitumens, but there are other substances entering into their composition which contain, in addition to carbon and hydrogen, sulphur, nitrogen, and more rarely oxygen. They consist of cyclic compounds containing an atom of sulphur or nitrogen in the carbon ring, compounds which are, in asphalt, dicyclic and polycyclic, and oxygen derivatives, probably polycyclic phenols, together with oxidation products of the hydrocarbons. As these constitute but a minor portion of native bitumen they will not be described in detail here. They can be readily separated from the hydrocarbons by appropriate reagents, but have not been closely studied. They are also found in various dense petroleums.

The nature and structure of the hydrocarbons and their derivatives have been entered into with some detail since the relative proportion of the various series which are present in any petroleum or solid bitumen has a strong influence on its characteristics, and, more especially, the relation of saturated to unsaturated hydrocarbons and of the paraffines to polymethylenes, these considerations being, of course, quite apart from the relative amounts of liquid and solid substances, malthenes and asphaltenes, upon which the consistency of the bitumen, but not its chemical characteristics, are based.

The saturated hydrocarbons, especially those of the paraffine series which are found in the residues from the distillation of Pennsylvania petroleum and of those from Ohio, Kentucky, Kansas, and similar oils, are most stable. They are not readily attacked by strong acids, alkalies, or water They form by far the largest part of the residuums derived from these petroleums. The saturated hydrocarbons of the polymethylene series found in some residuums as well as in the solid bitumens are not attacked by acids or water, but are readily condensed by the abstraction of hydrogen under certain other conditions. The polymethylene hydrocarbons or the petroleums containing them are in this way the primary source of all asphalts. No asphalt can originate in nature in a paraffine oil, but all polymethylene oils leave an asphaltic residue on weathering or on evaporation or distillation with heat.

No solid native bitumen suitable for paving purposes is known which contains paraffine, while the relative proportions of saturated and unsaturated hydrocarbons in them may be very variable.

The characterization of heavy oils or of solid bitumens and their differentiation is, therefore, arrived at by determining by appropriate analytical methods and by treatment with reagents the relative proportion of the malthenes and asphaltenes present, the proportions of saturated to unsaturated hydrocarbons in the malthenes, and the characteristics of all these classes of bitumens. The asphaltenes are probably composed entirely of unsaturated or unstable compounds.

SUMMARY.

For a thorough understanding of the nature of the native bitumens the constitution of the various hydrocarbons of which they may be composed has been outlined in the preceding chapter. This involves some knowledge of chemistry and may, therefore, be somewhat unintelligible to the general reader, but the statements here presented are entirely necessary in any treatise which aims at being at all complete in its consideration of the subject of the native bitumens and of asphalt paving mixtures.

CHAPTER VI.

CHARACTERIZATION AND CLASSIFICATION OF THE NATIVE BITUMENS.

In a recent article on the " Bitumens of Cuba " the author has shown that while there have been numerous attempts to define the nature of bitumen, and to characterize and classify the various forms, none of them has been satisfactory, and that this has been plainly due to the fact that it is only recently that a sufficient number of deposits have been studied in their native environment, and in the laboratory, by methods which were sufficiently developed to reveal anything as to the constitution of the harder forms. For example, the fact that hard bitumen in the form of asphalt consists of cyclic polymethylenes of two or more rings, of the condensation products of such hydrocarbons and of their derivatives, and that this form of bitumen is without doubt the result of the metamorphism of cyclic petroleums by natural causes has only been made apparent within the last few years.

This lack of data to serve as a basis of comparison and characterization of species, and as an aid to the close definition of what bitumen is, and how its various forms can be differentiated, has been largely supplied, as far as the harder forms—maltha, asphalt, gilsonite, grahamite, albertite, etc.—are concerned, by the examination in the author's laboratory of several hundred occurrences of these materials, scattered over the greater portion of the United States and Canada, the West Indies, and the northern coast of South America. Our knowledge of the nature of various forms of petroleum has also been greatly extended by the work of C. F. Mabery, C. E. Coates, E. O'Neill, and numerous continental chemists, and that of natural gas by F. C. Phillips and others.

There is, of course, a vast field still open for research, but it is believed that the presentation of the subject here given is based on more complete evidence than anything heretofore attempted.

What is Bitumen?—The most rational way of approaching the question appears to be to present the definitions and characterization of this class of materials as a whole, and then of the particular forms as they may be differentiated by the available evidence; that is to say, to put the results which have been reached before the reader, and then to show how these have been arrived at from the data and evidence available.

As a beginning, bitumen and pyrobitumen must be defined:

Native Bitumens and Pyrobitumens.—Native bitumens consist of a mixture of native hydrocarbons and their derivatives, which may be gaseous, liquid, a viscous liquid or solid, but, if solid, melting more or less readily on the application of heat, and soluble in turpentine, chloroform, bisulphide of carbon, similar solvents, and in the malthas or heavy asphaltic oils. Natural gas, petroleum, maltha, asphalt, grahamite, gilsonite, ozocerite, etc., are bitumens. Coal, lignite, wurtzilite, albertite, so-called indurated asphalts, are not bitumens, because they are not soluble to any extent in the usual solvents for bitumen, nor do they melt at comparatively low temperatures nor dissolve in heavy asphaltic oils. These substances, however, on destructive distillation give rise to products which are similar to natural bitumens, and they have been on this account defined by T. Sterry Hunt as "pyrobitumens," which differentiates them very plainly from the true bitumens. They usually contain oxygen, whereas the true bitumens, as a rule, do so to only a limited extent.

There is, of course, no sharp dividing line between bitumens and pyrobitumens, as the former are gradually metamorphosed by time and exposure to varied environment into the latter.

Classifications of Bitumens.—Among the bitumens there are such variations in physical attributes and chemical composition that they may be differentiated as follows:

BITUMENS:
- GAS.
  - *Natural hydrocarbon gases.*
  - *Marsh-gas.*

PETROLEUM.

Paraffine-oils.

Consisting of hydrocarbons and their derivatives, the lower members of which belong entirely to the paraffine series and have the general formula C_nH_{2n+2}.

(1) Those containing C_nH_{2n+2} hydrocarbons up to $C_{28}H_{58}$ with but traces of sulphur derivatives: Pennsylvania, West Virginia, Kentucky, Kansas, Colorado, etc.

(2) Those containing C_nH_{2n+2} hydrocarbons up to $C_{11}H_{24}$ and above that C_nH_{2n} and C_nH_{2n-2} polymethylenes with considerable amounts of sulphur derivatives: Ohio, Canada.

Cyclic Oils.

Consisting principally of polymethylene hydrocarbons of the series C_nH_{2n}, $C_nH_{2n-2}+C_nH_{2n-4}$, together with a certain amount of unsaturated hydrocarbons and their derivatives.

(1) Stable polymethylenes, consisting largely of naphthenes, C_nH_{2n}: Russian oils.

(2) Less stable polymethylenes together with considerable amounts of unsaturated hydrocarbons and their nitrogen and sulphur derivatives, and leaving an asphaltic residue on distillation: California.

Oils of Mixed Composition.

Semi-asphaltic oils composed largely of stable paraffine and polymethylene hydrocarbons not readily attacked by sulphuric acid: Texas.

MALTHA.

Known also as mineral tar, brea, and chapapote.

Originating from polymethylene petroleums alone.

Transition products between oil and asphalt.

SOLID BITUMENS.

Consisting largely of paraffine hydrocarbons.

Ozocerite, hatchettite, etc.

Consisting of unsaturated cyclic hydrocarbons.

Terpenes, fossil resins, amber, etc.

Derived from or originating in polymethylene petroleums, the more volatile components consisting of di- or tricyclic saturated hydrocarbons.

Asphalts.

Asphalt. Numerous varieties: Trinidad, Venezuela, California, Cuba.

Glance pitch.

Consisting largely of cyclic hydrocarbons attacked by strong sulphuric acid, but which otherwise are stable.

Manjak.

Yielding high fixed carbon and a black powder.

Gilsonite.

Yielding average fixed carbon and a brown powder, the more volatile components resembling sticky oleo resins rather than hydrocarbons found in the asphalts.

Grahamite.

Consisting of hydrocarbons almost entirely insoluble in naphtha and yielding a higher percentage of fixed carbon on ignition. Melting with difficulty.

The grahamites rapidly shade into pyrobitumens.

PYROBITUMENS:

Practically insoluble in chloroform or heavy petroleum hydrocarbons.

Derived from petroleum.

Albertite, with varieties called nigrite, etc.

Wurtzilite.

Derived from direct metamorphoses of vegetable growth.

Anthracite.

Bituminous coal.

Lignite.

Peat (?).

Of the bitumens, as we have seen, the hard ones and the oils enter into the composition of paving cements and must be considered individually.

SUMMARY.

The author's classification of the native bitumens and those of other writers are unfortunately founded on an empirical basis to too great a degree to admit of their being satisfactory to every one. Such classifications can be regarded as mere steps toward a final conclusion which can only be arrived at after years of investigation of the subject. The author's classification is presented for what it is worth, and there will be no hesitation in modifying it in the future in the light of any additional information which may become available which is based on facts and not on mere opinion or theory. For a thorough understanding of the character of the native bitumens it is advisable that the general reader should acquaint himself with the peculiarities of the different classes which it has been possible to differentiate, the one from the other, in order that an intelligent understanding may be arrived at of the very variable nature of the bitumens in use in the asphalt paving industry.

The mere minute differences in the various bitumens, upon which their differentiation has been based, will be made plain in the following pages.

PART III.

NATIVE BITUMENS IN USE IN THE PAVING INDUSTRY.

INTRODUCTION.

In the light of the preceding classification of the native bitumens and our knowledge of the various series of hydrocarbons of which they are composed the characteristics of the fluxes, the asphalts, and other solid native bitumens in use in the paving business may now be taken up.

CHAPTER VII.

DIFFERENTIATION AND CHARACTERIZATION OF THE NATIVE BITUMENS.

All the native bitumens are such complicated mixtures of various hydrocarbons and their derivatives that it is impossible to separate them completely into their individual constituents and to differentiate and characterize them in this way. Recourse must, therefore, be had to the determination of their physical properties and to attempts, more or less successful, to separate the proximate constituents of which they are made up into various classes according to their solubility and behavior towards reagents, supplemented by the determination of the amount of fixed carbon which they yield on ignition and their ultimate composition.

Physical Properties.—The physical properties which are of value in characterizing the bitumens are:

SOLID BITUMENS.

PHYSICAL PROPERTIES.

Specific gravity, 78° F./78° F. Original substance, dry
" " " Pure bitumen .... ——
Color of powder or streak........................ ——
Lustre.................................... ——
Structure.................................. ——
Fracture................................... ——
Hardness, original substance...................... ——
Odor...................................... ——
Softens.................................... ——
Flows..................................... ——
Consistency, penetration at 78° F.................. ——

The chemical characteristics of interest are:

CHEMICAL CHARACTERISTICS.

Original substance.............................. ——
Loss, 212° F., 1 hour.......................... ——
Dry substance................................ ——
Loss, 325° F., 7 hours......................... ——
Character of residue.......................... ——
Consistency, penetration of residue at 78° F....... ——

Loss, 400° F., 7 hours (fresh sample)............. ——
Character of residue.......................... ——
Consistency, penetration of residue at 78° F....... ——

Bitumen soluble in CS_2, air temperature............ ——
Inorganic or mineral matter...................... ——
Difference.................................. ——

Malthenes:
Bitumen soluble in 88° naphtha, air temperature... ——
This is per cent of total bitumen................. ——
Per cent of soluble bitumen removed by H_2SO_4.... ——
Per cent of total bitumen as saturated hydrocarbons. ——

Bitumen soluble in 62° naphtha.................. ——
This is per cent of total bitumen................. ——
Carbenes:
Bitumen insoluble in carbon tetrachloride, air temperature .... ——

Bitumen yields on ignition:
Fixed carbon.............................. ——

Sulphur.................................... ——

Ultimate composition........................... ——

FLUXES.

PHYSICAL PROPERTIES.

Specific gravity, dried at 212° F., 78° F./78° F.	——
Flows, cold test.	——
Color	——
Odor.	——
Under microscope	——
Flashes, ° F., N. Y. State oil-tester.	——
Viscosity P.R.R. pipette at – ° F.	——

CHEMICAL CHARACTERISTICS.

Original substance.	——
Loss, 212° F., 1 hour or until dry	——
Dry substance.	——
Loss, 325° F., 7 hours.	——
Character of residue.	——
Penetration of residue at 78° F.	——
Loss, 400° F., 7 hours (fresh sample).	——
Character of residue.	——
Penetration of residue at 78° F.	——
Bitumen soluble in CS_2, air temperature.	——
Inorganic or mineral matter	——
Difference	——
Bitumen insoluble in 88° naphtha, air temperature, pitch.	——
Per cent of soluble bitumen removed by H_2SO_4	——
Per cent of total bitumen as saturated hydrocarbons	——
Per cent of solid paraffines.	——
Fixed carbon.	——
Ultimate composition.	——

Specific Gravity.—For the physical characteristics it may be said that the specific gravity of the solid bitumens as they are originally found in nature will depend very largely upon the percentage of mineral matter which they contain. One like Trinidad lake asphalt, containing 37 per cent of mineral matter, will have a specific gravity of 1.40, while an extremely pure bitumen, like gilsonite, will have a specific gravity of 1.04.

Where the pure bitumen is extracted from the native material the density will not, as a rule, vary very widely. For the asphalts it will lie between 1.03 to 1.07.

Ozocerite is the only solid bitumen which has a specific gravity below 1.00, .912, while grahamite, albertite, and glance pitch exceed a density of 1.09.

The density of the residual pitches, at least of those met in the paving industry, is usually quite similar to that of the bitumens of the native asphalts, not rising above 1.1, unless in their preparation they have been carried to a very high temperature, nor falling below 1.0 if they are at all solid. Some of the condensed oils, such as Byerlyte, Pittsburg flux, and blown asphaltic oil, have a density below 1.0 and can be recognized by the fact that they float on water.

The specific gravity of the various bitumens is, therefore, of some considerable interest.

A summary of some of the data collected by the author is given in the following table:

Substance.	Specific Gravity.
Trinidad lake refined asphalt	1.4000
“ land “ “	1.4196
Bermudez refined asphalt—1900	1.0823
“ “ “ —1903	1.0575
Maracaibo refined asphalt	1.0667
Cuban (Bejucal) asphalt	1.3050
Mexico—Tamesi River asphalt (dry)	1.1180
“ —chapapote asphalt (dry)	1.0450
California—La Patera	1.3808
“ —Standard, refined	1.0627
Utah—gilsonite firsts	1.0433
“ — “ seconds	1.0457
Grahamite—Indian Territory, Ten Mile Creek	1.1916
“ —Colorado, Middle Park	1.1600
Egyptian glance pitch	1.0970
Manjak	1.0844
Ozocerite—Utah	0.9123
Albertite—Nova Scotia	1.0790
“ —Utah	1.0990
“ —Cuba	1.2040
Wurtzilite—Utah	1.0556
Kentucky, Grayson Co.—seepage	0.9783

Substance.	Specific Gravity.
Utah, Soldier Creek—extracted bitumen......	1.2000
" Grand Co.—extracted bitumen..	1.0370
"D" grade Califorina, carefully prepared.....	1.0622
" " " carelessly "	1.0887
" " " Asph. O. & Ref. Co....	1.0770
Beaumont, Texas, oil asphaltic residue.......	1.0803
Baku pitch from Russian petroleum.........	1.1098
Pittsburg flux..........................	0.9879
Ventura flux............................	1.0199
Byerlyte, paving.........................	1.0230
" roofing.........................	0.9070
Hydroline "B".........................	1.0043

Color of Powder or Streak.—Where the solid native bitumens are sufficiently hard to permit of their being powdered or to make a streak upon porcelain, the color of the powder or streak may be of some value in differentiating them. For example, the powder of refined Trinidad lake asphalt is of a bluish-black color, whereas that of Trinidad land asphalt is distinctly brown. Most of the asphalts give a powder of either a dull-black or brownish-black color, but gilsonite is distinguished by its extreme brittleness and the fact that the powder is of an extremely light-brown color.

Lustre.—All the native bitumens are lustrous if pure, with the exception of ozocerite. The residual pitches are, of course, lustrous. In the presence of mineral matter the lustre is more or less diminished, depending upon the amount of the latter.

Structure.—The structure of the native bitumens is in many cases very characteristic. To begin with, it is either uniform and homogeneous in every part or the reverse. In crude Trinidad lake asphalt we note the presence of gas cavities and of emulsified water. In some California asphalts large particles of brecciated shale are scattered through the native asphalt, which occurs in veins. On the other hand, gilsonite is of an extremely uniform structure except where the material approaches the vein wall, where it at times takes on a columnar structure due to weathering. Glance pitch and manjak are also of extremely uniform structure. The same thing may be said in regard to many refined asphalts in which the lack of homogeneity has been removed by melting. The structure of the residual pitches is, of course, quite homogeneous, except where they may have been coked to a certain degree by excessive heating.

Fracture.—The fracture of the native solid bitumens in many cases is as characteristic as the structure. Almost all grahamites, although homogeneous in structure, have a peculiar fracture which distinguishes them from all the other solid bitumens. It has been described as a hackley or pencilated fracture, which, perhaps, covers it sufficiently. It is an irregular fracture and shows no evidence of a purely lustrous surface, as in the fracture of gilsonite. The fracture of crude Trinidad asphalt is quite irregular, that of gilsonite conchoidal and highly lustrous, while that of many refined asphalts is only semi-conchoidal.

Hardness.—The hardness of the native bitumens in the form in which they originally occur may be stated in terms of Mohr's scale. Where the pure bitumen is softer than 1 of this scale, it may be stated in terms of one of the various penetration machines.

Odor.—The odor of most of the native bitumens is characteristic at ordinary temperatures. The asphalts have in general an asphaltic odor, but some of them, such as that from near the Gulf of Maracaibo, in Venezuela, are characteristically rank. Gilsonite has scarcely any perceptible odor, while the residual pitches have a peculiar oily odor. On heating, stronger odors are commonly developed which are recognizable to one accustomed to them, but the nature of which is difficult to describe in print.

Softening and Flowing Points.—The native bitumens possess no melting-point. It can be stated that they are in a melted condition at such and such a temperature, but since they are made up of a mixture of hydrocarbons and their derivatives it is impossible for them to have a true melting-point, such as that of ice or any definite compound. In cooling a mass of water in which a thermometer is immersed from any temperature, say 50° F., to a point below freezing and representing this on a system of coordinates, the time being denoted by the abscissæ and temperature by the ordinates, a curve will be developed which at the point of freezing, while the water is being converted into ice, is broken by a straight line which denotes the time during which the liquid is becoming converted to ice. If any native bitumens are melted and cooled in the same way no definite break corresponding to any definite freezing-point is detected. It is, therefore, impossible for us to speak of the melting-point of a bitumen, but we may determine in any empirical way the point at which any solid bitumen softens and again when it flows, as specified in the author's method given in Chapter XXVIII. The determinations of this nature given in the following pages were made in this way.

Chemical Characteristics.—It will be noted that in the differentiation of the bitumens into classes by means of solvents, certain names have been applied to the various classes of hydrocarbons. In the early days of the study of the behavior of solvents towards native bitumens, the various hydrocarbons and their derivatives were differentiated, according to their solubility in naphtha, into classes to which the names "Petrolene" and "Asphaltene," terms used by Boussingault in his earliest investigations, were applied. These terms were open to the objection that it led persons not thoroughly acquainted with the chemistry of the natural hydrocarbons to believe that petrolene and asphaltene were definite compounds, which, of course, is no more the case than to assume that the oil known under the name kerosene is a definite compound. The author, therefore, changed the designation to "Petrolenes" and "Asphaltenes" as more plainly indicating that the differentiation was merely one of classes. More recently it has seemed possible to carry the differentiation still further, since it has been found that the solubility of the native bitumens in cold carbon tetrachloride is not in all cases the same as in bisulphide of carbon or chloroform and that solubility or insolubility in this medium can be added to those previously employed for this purpose. Peckham has also shown that chloroform dissolves hydrocarbons which are not soluble in carbon disulphide, and this solvent may be added to our list, or even oil of turpentine if thought necessary. The author's idea in regard to the future differentiation of the native bitumens would involve the application of the term "Malthenes," to the bitumens soluble in naphtha in place of the term "Petrolenes," stating the specific gravity of the naphtha used as a solvent, as this class of bitumens bears a great resemblance to the malthas; reserving the term "Petrolenes" for those hydrocarbons which are volatile at 325° F. in 7 hours, according to the author's method, these hydrocarbons being comparatively light oils resembling ordinary petroleum. He would characterize as "Asphaltenes" those hydrocarbons and their derivatives which are soluble in cold carbon tetrachloride and as "Carbenes" those not soluble in cold carbon tetrachloride, but soluble in carbon disulphide. This differentiation has not been carried out in the author's work to any great extent in the past, but in many cases in the following tables the percentage of the bitumen insoluble in cold carbon tetrachloride will be found to prove of great interest.

In the determination of the amount of fixed carbon which any native bitumen will yield when heated to a high temperature in the absence of oxygen, after the manner proposed for making the same determination in coal, data are obtained which are of great interest as showing the relative proportion of carbon and hydrogen in the bitumen under examination. In the case of the paraffine hydrocarbons of the formula C_nH_{2n+2} no fixed carbon is left on ignition, while the amount increases with each diminution in the proportion of hydrogen to carbon, until in grahamite as much as 50 per cent is found, where the relation of carbon to hydrogen is as 8 to 1.

The ultimate composition of the bitumens is, of course, of interest, but for general purposes the information derived from this determination seldom repays the time and care necessary.

The methods employed in arriving at the results which are presented in the following tables are given in a later chapter of this book, and reference must be made to it for the details of the process and for a thorough understanding of what each determination may mean.[1]

It will be found on examining these methods that the results obtained by their use are in no sense absolute determinations, but when each of the asphalts is treated in quite the same way as the others they are of great value relatively and for purposes of comparison and differentiation. In regard to certain of the data some explanation will be necessary.

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[1] Page 519.

Bitumen Soluble in Bisulphide of Carbon, Air Temperature.—This determination shows the amount of bitumen which is soluble in cold bisulphide of carbon. If hot bisulphide of carbon, chloroform, or turpentine and in some exceptional cases hot carbon tetrachloride are used as a solvent, a slightly larger percentage would probably be found but, owing to the difficulties in maintaining uniform conditions for extraction at other than ordinary temperatures and for other reasons which it is unnecessary to specify here, cold bisulphide of carbon has been used and the results obtained are more satisfactory for comparative purposes than would otherwise be the case.

Inorganic Matter.—The determination of inorganic or mineral matter represents the residue remaining on the ignition of the native bitumen in a muffle at such a temperature as to remove all the carbon. In certain cases the amount obtained may be less than that originally present, owing to the volatilization of alkalies or sulphuric acid, but it is sufficiently accurate for purposes of comparison.

Insoluble or Difference.—On adding together the percentages of bitumen soluble in carbon disulphide and of inorganic matter obtained on ignition, the sum will seldom amount to 100.0. The difference which is stated as such in our analyses has for many years been considered as organic matter not bitumen. This may be true in exceptional cases, but recent investigations[1] have shown that it is not at all so in many bitumens. For example, in Trinidad asphalt it has been found to consist of the water of combination of the clay which the material contains and some inorganic salts which are volatilized on ignition. The amount of organic matter is extremely small. In other cases, it may consist to a considerable extent of grass and twigs, as in the seepages which have run out over sod. On the whole, therefore, it seems desirable not to describe it by any definite name, but merely as an undetermined difference.

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[1] Proc. Am. Soc. Test. Mat., 1906, 6, 509.

Loss at 325° F. in 7 hours.—The hydrocarbons lost at 325° F., which the author has proposed to denominate "Petrolenes," as a class, will vary in amount enormously according to the conditions under which the heating is carried out. When these are accurately defined, however, as in our methods, the relative loss is an important indication in differentiating any two bitumens.

Malthenes.—It is a well-known fact that the percentage of malthenes or bitumen soluble in naphtha will vary according to the solvent used, and in the case of naphtha if its density is low, according to the method by which the solvent is applied. In the determinations given in the table naphthas of a definite density, 88° and 62° Beaumé, have been allowed to act on the native bitumen, in as finely a comminuted condition as possible, in the cold for a definite length of time and the residue washed quite clean with the same solvent. Had the solvent been applied warm or in a continuous percolation apparatus the figures would have been higher but would not have been constant, since the lighter hydrocarbons in the solvent would have been gradually volatilized and their solvent power slowly increased. For comparative purposes the method in use is more satisfactory than any other, but the results themselves are of no value as an absolute differentiation of the native bitumen into two definite classes of materials.

Action of Strong Sulphuric Acid on the Hydrocarbons.—The results presented showing the action of strong sulphuric acid on the hydrocarbons soluble in 88° naphtha are only of value because all of them are carried out according to a definite and arbitrary method. If this were varied the results would also vary. It is important to know that strong sulphuric acid has a somewhat different action on the hydrocarbons of a solid bitumen if it is allowed to act on an 88° or 62° naphtha solution of them. In the 62° naphtha solution the action is apparently much less than in the solution of the solvent of lighter density.

Bitumen Insoluble in Carbon Tetrachloride, Air Temperature.—The amount of bitumen soluble in cold carbon tetrachloride, in all the normal asphalts, is practically the same as that soluble in carbon disulphide, but in certain native bitumens hydrocarbons are found which are insoluble in this medium. This differentiates these bitumens—grahamite, for example—from the true asphalts, the insoluble bitumen forming a class of hydrocarbons or of their derivatives to which the name of "Carbenes" has been applied. Such bitumens have evidently been much more metamorphosed by weathering or otherwise than the true asphalts, or have originated in a different series of hydrocarbons.

In residual pitches, at times some of the bitumen is found which is insoluble in cold carbon tetrachloride, and this is evidently due to the severe treatment which the material has suffered in the course of its production at very high temperatures. A determination of the amount is only valuable as an indication of the care which has been used in the preparation of such pitches. In the best asphaltic residues from California petroleum the percentage of "Carbenes" has been found to vary from 7 to less than one-half of 1 per cent.

Fixed Carbon.—The amount of fixed carbon which any solid native bitumen will yield will depend, as in the case of coal, upon the way in which the material is ignited. All the determinations given have been made by following the scheme suggested by the Committee of the American Chemical Society on the Analysis of Coal, and are, therefore, strictly comparable.

With these facts in view the analyses of the native bitumens which are to be presented will be of interest for the purpose of comparing the characteristics of the various materials, but the chemical data must not be looked upon as being absolute in any case.

SUMMARY.

By determining the physical characteristics of any native bitumen, its specific gravity, its color in a powdered condition, its lustre, structure, fracture, hardness, odor, softening point, and consistency, by differentiating the bitumen into various classes of hydrocarbons by means of solvents and by observing certain other chemical characteristics, such as the ultimate composition, the amount of fixed carbon left on ignition, and the extent to which the hydrocarbons of which it is composed are acted upon by strong sulphuric acid, it is quite possible to characterize and classify the various native bitumens in such a way as to make it possible to recognize them without difficulty and without confusing one with another. The methods for making these determinations appear in Chapter XXVIII.

CHAPTER VIII.

PETROLEUMS.

In the asphalt paving industry the petroleums are of interest because the heavier hydrocarbons or residuum which remains on distilling off the lighter portion of the oil are used as a flux for the solid native bitumens. The character of these residuums and fluxes reflects, of course, the nature of the petroleum from which they have been made, the paraffine oils yielding a residuum of one kind, the asphaltic oils one of another, and the mixed paraffine and asphaltic oils, such as those from the Beaumont field and elsewhere in Texas and from Oklahoma and part of Kansas, one of quite another character.

For a more definite knowledge of the proximate composition of various petroleums, beyond that which has been given in the classification, reference must be made to the publications of those who have devoted their time to a study of this subject, among whom may be named Mabery, Young, Markownikoff, and Engler. Unfortunately the publications of these investigators are widely scattered and appear nowhere in condensed form. Their general conclusions have been included in the author's classification of petroleums.

Malthas.—The malthas are viscous liquid natural bitumens corresponding in consistency to that of the artificial residuums or usually denser. They are only rarely of a suitable character for use as a flux, owing to the fact that on heating they are generally rapidly converted into a harder material by the loss of volatile hydrocarbons and condensation of the molecule. It was due to this fact that the early pavements laid with Alcatraz asphalt were not successful. The flux in use was a natural maltha derived from the Carpinteria sands, which, while of the proper consistency as prepared, was rapidly converted into a solid bitumen on prolonged heating.

The bitumen in the Kentucky sands is much more of the nature of a maltha than of an asphalt, and it is on this account that these materials are unsatisfactory for paving purposes in addition to the fact that they contain usually a much too small percentage of bitumen.

For the above reasons the native malthas are rarely used in the preparation of asphalt cement and never with successful results.

On page 129 are given some examples of the characteristics of malthas from various parts of the world.

It appears that the malthas may, when dry but not otherwise altered, have a specific gravity either less or greater than water. They all volatilize a very considerable amount of light oils at 325° F., and most of them large amounts at 400° F. In the case of four out of nine of those cited the residue after heating to only 325° F. was hard enough to permit a determination of their consistency with the penetration-machine. Under the same circumstances a paraffine residuum would still remain a flux, as would the best asphaltic petroleum residuums. They frequently contain notable percentages of the asphaltenes and all become pitch after heating to a constant weight at 400° F.

The Residuums of Petroleums Used as Fluxes in Softening the Solid Native Bitumens.—In order to bring the solid native bitumens to such a consistency as will make them available for use as a paving-cement it is generally necessary to flux them with some other softer bitumen. The flux in use for this purpose is uniformly a heavy residuum prepared by the removal of the lighter portions of petroleum by distillation. These residues naturally vary in character in the same way that the petroleums do from which they have been derived, and that the petroleums are very variable, depending upon the series of hydrocarbons of which they are composed, has already been made evident. The oils from which residuums or fluxes are prepared for use in the United States are the paraffine petroleums from the Eastern, Ohio, Kentucky, Kansas, Oklahoma, and Colorado fields, the asphaltic petro-

Characteristics of Malthas.	Test No.			
	30374. California, Sunset District.	30116. California, McKitrick District.	25129. Cuba, Hato Nuevo.	50912. Cuba, Matanzas.
Loss, 212° F.	......	......	7.76%	11.0%
Flash-point	245° F.	270° F.	......	325° F.
DRY SUBSTANCE.				
Specific gravity, 78° F./78° F.	.9867	.9884	.9445	1.0029
Loss, 325° F., 7 hours	7.0%	12.4%	5.8%	8.9%
Penetration of residue at 78°F.	*	*	38°	*
Loss, 400° F., 7 hours	28.0%	16.1%	......	13.2%
Penetration of residue	40°	*	......	*
Loss, 325° F. to constant wt.	......	......	......	22.8%
Penetration of residue	......	......	......	*
Loss, 400° F. to constant wt.	......	......	......	32.1%
Penetration of residue	......	......	......	16°
Bitumen insoluble in 88° naphtha, pitch	6.7%	......	25.5%	17.6%
Bitumen insoluble in 62° naphtha, pitch	......	......	15.7%	8.1%
Bitumen yields on ignition: Fixed carbon	......	......	......	8.6%

Characteristics of Malthas.	Test No.				
	39556. Venezuela, Pedernales.	10106. Venezuela, Mene River.	63846. Texas, Austin.	30283. Trinidad, Boodooshingh.	60487. Trinidad, Marabella.
Loss, 212° F.	9.7%	9.0%	1.5%	18.5%	5.2%
Flash-point	....	....	....	....	....
DRY SUBSTANCE.					
Specific gravity 78° F./78° F.	1.032	....	.974	....	....
Loss, 325° F., 7 hours	4.6%	8.5%	7.1%	10.4%	6.4%
Penetration of residue at 78°F.	75°	*	*	hard	32°
Loss, 400° F., 7 hours	11.1%	5.9%	17.0%	....	10.3%
Penetration of residue	23°	*	*	....	20°
Loss, 325° F. to constant wt.	....	....	....	....	....
Penetration of residue	....	....	....	....	....
Loss, 400° F. to constant wt	....	....	31.0%	....	....
Penetration of residue	....	....	13°	....	....
Bitumen insoluble in 88° naphtha, pitch	....	9.4%	3.5%	....	40.4%
Bitumen insoluble in 62° naphtha, pitch	....	....	....	....	25.9%
Bitumen yields on ignition: Fixed carbon	7.0%	....	....	....	10.0%

* Too large to read.

leums from California and the petroleum of mixed character from Texas containing both paraffine and asphaltic hydrocarbons. The residues from paraffine petroleum usually carry a very considerable amount of paraffine scale, which has a decided influence on their character. The residue from Texas petroleum from the Beaumont field, now nearly exhausted, contained only a small amount of paraffine hydrocarbons and not more than 1 per cent of paraffine scale. The supply of flux of this character is now very small, and is all produced at Chaison, Texas. The greater part of the Texas flux on the market in 1907 was produced from pipe line oil from the various Texas and Oklahoma fields. This petroleum is necessarily of a very mixed character and the flux prepared from it has contained very considerable amounts of paraffine hydrocarbons and scale, the latter reaching at times as high as six per cent. It is far less satisfactory as an asphaltic flux than that prepared from the original Beaumont oil, and in some respects is not a suitable substitute for it. For use with ordinary asphalts it is, however, as good for paving purposes, although perhaps not quite as stable at high temperatures. It must be used as a paraffine flux. The California residuum or flux is composed almost entirely of complicated polymethylenes and contains notable proportions of aromatic hydrocarbons, nitrogenous bases, and phenols, and is characterized by its very great density.

Residuums from the same kind of petroleum may, on the other hand, vary very largely among themselves, according to the care with which they have been prepared. It is quite as necessary, therefore, to determine whether a flux has been carefully distilled as it is to know the character of the petroleum from which it has been produced.

In making a comparative study of the available fluxes it will also be necessary to determine whether there is a preference in favor of one over another as an actual solvent for the solid bitumens, and to determine their stability and such other properties as may point to their adaptability for use in the preparation of an asphalt cement.

The fluxes now in use in the paving industry may be considered as consisting of the three classes which have been mentioned above, and their character may be taken up according to such a classification.

Paraffine Petroleum Residuum.—Paraffine petroleum residuum is the form of flux originally used in the asphalt paving industry in the United States. It is also known as petroleum tar and was originally a by-product remaining after the distillation of crude Pennsylvania paraffine petroleum for the production of illuminating-oil. It was the flux used by De Smedt in the early days of the paving industry for imparting a proper consistency to Trinidad asphalt in the production of paving-cement. Its use has been largely continued up to the present time, but its character has been greatly modified and improved. It is no longer a by-product, but is especially prepared for the purpose.

In the early days of the industry the residuum used in the preparation of asphalt cement was of most varied character. Among available records it is found that in the summer of 1888 several residuums in use had the following properties:

Flash.		Gravity.
230° F.	22° B.	.9240
203°	24°	.9130
226°	25°	.9070
392°	27°	.8950
428°	22°	.9240
176°		

The result of making a cement with oil flashing at 176° F. would be that much of it would be easily volatilized at the temperature of melted asphalt cement, 325° F., and that the consistency would of course be most unstable.

In 1889 the oils in use had the following characteristics:

Source.	Gravity.	Flash.	Volatile, 400° F.
Eagle Refining Co.	22.8° B.	416° F.	14.40%
Maloney Oil Co.	21.7°	361°	14.33
Jenney Mfg Co.	20.8°	271°	16.80

As late as 1892 the oils were still variable:

Source.	Gravity.	Flash.	Volatile, 400° F.
Solar	21.0° B.	417° F.	4.06%
Jenney	18.5°	235°	11.20
National	20.0°	295°	15.94
Whiting	22.2°	415°	5.39
Continental (Denver)	23.8°	345°	15.73
Crew Levick	20.4°	320°	17.36

In 1891 the Standard Oil Company undertook to prepare a heavy oil especially for paving purposes which should be furnished to those who were particular as to its character and were willing to pay for a better quality. It has had the following average composition since 1896:

PARAFFINE RESIDUUMS. AVERAGE AND EXTREMES IN COMPOSITION FOR FOUR YEARS.

Year.	Volatile, 400° F.	Extremes.	Specific Gravity.	Extremes.	Flash.	Extremes.
1896	4.7%	2.6– 8.8	.9313	.9204–.9351	430° F.	397°–476°
1897	6.1	1.4–12.3	.9302	.9219–.9383	420°	393°–456°
1898	5.1	2.9– 8.8	.9327	.9206–.9397	432°	392°–455°
1899	3.8	2.0– 6.4	.9331	.9295–.9376	442°	416°–460°

Consistency after heating: Flows slowly at about 78° F.

The great uniformity of the supply is apparent. Oil of the old character is still in use by careless contractors, as it is cheap. Oils of this description which have come under my observation have the following characteristics:

Specific Gravity.	Flash.	Volatile, 400° F., 7 Hours.
.9100	280° F.	23.9%
.9197	330°	17.3
.8829	260°	27.2
.9222	286°	12.6

The best paraffine residuum from Ohio petroleum and some of the Kansas and Colorado fields, which has been in use during the past six or seven years has commended itself in quality from the fact that it is carefully prepared for the paving industry by distillation with steam agitation without cracking—that is to say, decomposition of the oil—that it has a high flash point, and on this account contains little oil volatile at the temperatures at which asphalt cement is maintained in a melted condition, and that it is uniform. The possible disadvantages of such dense residuum, if they are such, in comparison with the lighter and more volatile oils are, that more of this oil must be used to produce a cement of given penetration or consistency and that at comparatively low temperature asphalt cements made with it harden more than when lighter oils are used, owing to the separation of paraffine scale.

The only advantage of the lighter form of residuum, however, is the one just mentioned, that it and the cement prepared from it do not harden or solidify as much in winter temperatures.

Typical Paraffine Fluxes of 1907.—In the following table are given the characteristics of various paraffine fluxes which were available and in use in the paving industry in the year 1907. Many of the paraffine fluxes, analyses of which were given in the original edition of this work, are no longer available, and there is no assurance that the supply for any one year can be duplicated the following one.

Character of flux	Paraffine	Paraffine	Paraffine
Manufacturer	Solar Ref. Lima, Ohio	S. O. Co. Whiting, Ind.	S. O. Co. Neodesha, Kan.
Date shipment received	10-28-07	10-30-07	11-10-07
Test number	100537	100610	100446
Sp. gr.—Beaumé—at 78° F.	18.4	20.5	21.2
Sp. gr.—actual—at 78° F.	.943	.930	.926
Flash point, degrees F.	455	425	435
Volatile 7 hours, at 212° F.	.1%	.2%	.4%
Volatile in 7 hours, 325° F. (dry sample)	.2	1.2	.6
Residue at 78° F.	Crystalline Slow flow	Crystalline Quick flow	Crystalline Quick flow
Bit. insol. 88° naphtha, pitch	2.7	3.4	2.6
Per cent sol. bit. rem. by H_2SO_4	24.9	24.7	25.9
Paraffine scale	6.4	7.9	8.9
Fixed carbon	2.8	1.9	1.8

The petroleum residuum used in the work carried out under the author's supervision is furnished under the following specifications:

Specifications for Paraffine Flux, 1907-1908.—"This oil or flux shall consist of the heavier or higher boiling portions of any paraffine petroleum. It shall have a specific gravity of between .942 and .924 (18.6–21.5° B.) at 78° F.

"It shall be free from water and decomposition products, shall contain not more than 2% of bitumen insoluble in 88° naphtha, not more than 10% of material recovered when one gram of the flux is treated as for the determination of paraffine scale, according to the method described in "The Modern Asphalt Pavement," John Wiley & Sons, and shall not volatilize more than 5% at 325° F. in 7 hours."

It appears from the preceding table and from our specifications that a residuum from a paraffine petroleum, such as used in the asphalt industry at the present day, if it is in the highest degree desirable, should have a specific gravity of .93, equivalent to a density of 21.0° B., a flash point of 400° F., should volatilize but a small amount at 325° F. under certain conditions which are imposed, should be practically completely soluble in carbon disulphide, and to the extent of 95 per cent in 88° naphtha. The paraffine scale should be less than 10 per cent, and the amount of fixed carbon which is obtained on ignition not over 4 per cent.

It will be noted in the preceding analyses that the percentage of paraffine scale varies, in the samples examined, from 6.4 to 8.9 per cent. In other residuums even more paraffine scale has been found, as can be seen from the following determinations which were made some years ago in the author's laboratory.

Manufacturer.	Paraffine.
Craig Oil Co., Milwaukee	17.6%
Crew Levick Co., Philadelphia	8.7
American Petroleum Product Co., Findlay, Ohio	12.3
Scofield, Shurmer & Teagle, Indianapolis, Ind.	7.1
Standard Oil Co.	14.5
Wilburine Oil Co., Brooklyn	33.3
Standard Oil Co., thin oil	9.1

The smaller the amount of paraffine scale that is present the more desirable the flux, since a substance of this nature which becomes solid at low temperatures cannot be advantageous in a paving cement. That paraffine residuum is an extremely stable oil appears from the fact that about 75 per cent of the hydrocarbons of which it is composed are not attacked in 88° naphtha solution by concentrated sulphuric acid, a fact which is confirmed by exposing such a residuum to water for many years, when no action is found to have taken place.[1]

The characteristics of asphalt cement made with paraffine residuums of various densities, and the refutation of the claim that it is not a satisfactory solvent for asphalts and is unsuited for the purpose for which it is used in the paving industry, will be taken up later when asphalt cements are under consideration. It is merely necessary to state here that of such a residuum as has been described from 18 to 22 pounds must be used with every 100 pounds of refined Trinidad lake asphalt in order to produce a cement of proper consistency for paving purposes.

Kansas Petroleum Residuum.—Within the last two years a flux has appeared on the market which is prepared from the oils coming from the Kansas fields through pipe lines to the East. This flux is very peculiar in character. It possesses largely the characteristics of a paraffine, and some of those of an asphaltic flux. It is peculiar in that, although it carries but 6.7% of paraffine scale, it leaves a solid, cheesy residuum amounting to 85% of the original oil on heating at 400° F., while, on being maintained at that temperature for a considerable period of time, it decomposes with the separation of a granular insoluble material, and with the evolution of gas. On this account it is looked upon by the author as more or less unsuitable. It has been used to a very large extent, however, and apparently works satisfactorily at ordinary temperatures with Trinidad and Bermudez asphalt. It is to-day one of the largest sources of supply of flux in the paving industry and its value can only be shown by service tests. In the meantime, it must be classed as a paraffine residuum.

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[1] Whipple & Jackson, The Action of Water on Asphalt. Engineering Record, March 17, 1900, 41.

Its characteristics are shown in the following table:

Manufacturer	Standard Oil Company, Brooklyn, N. Y.
Received from	Maurer, N. J.
Date shipment received	5-10-08
Test number	2857-M.
Specific gravity—Beaumé—at 78° F.	19.4°
Specific gravity—Actual—at 78° F.	.937
Flash point, degrees F.	485
Volatile in 7 hours at 212° F.	.2%
Volatile in 7 hours at 325° F. (dry sample)	.6%
Residue at 78° F.	Medium slow flow—crystalline
Volatile in 7 hours at 400° F. (dry sample)	2.0%
Residue at 78° F.	Medium flow—crystalline
Bitumen insoluble in 88° naphtha, pitch	2.7%
Per cent soluble bitumen removed by H_2SO_4	23.4
Paraffine scale	2.5
Fixed carbon	3.5

California Asphaltic Petroleum Residuum.—The petroleums of California are characterized by the fact that the residue left on distillation, if the latter is carried sufficiently far, is a solid bitumen resembling asphalt. The oil is said, on this account, to have an asphaltic base. If the distillation is suspended at a point where the residue does not solidify on cooling but remains liquid, like a heavy and dense natural maltha, the material known as California flux is obtained which has been in use in the paving industry to a very considerable extent on the Pacific Coast and to but a small extent elsewhere. Such residuums, as found on the market in 1907, have the characteristics given in the table on page 137.

Before discussing the characteristics of these residuums it will be necessary to consider what takes place in the process of their manufacture. The petroleum is distilled in cylindrical stills in the usual manner with some steam agitation, the temperature being eventually carried up to about 600° F. or higher, and maintained there until a sample is slightly heavier than water when poured into it. It is very evident that in this process the petroleum is subjected to a very severe treatment and it is not difficult to determine at the plant where such flux is produced that very decided cracking goes on. That such cracking takes place can also be shown by heating a small portion of the original petroleum in a glass dish in an oven at not over 400° F., when the lighter portions all volatilize without cracking and the residue recovered

CALIFORNIA ASPHALTIC PETROLEUM RESIDUUM.

Test number	68489	69607
Trade name	"No. 2"	"G" grade
PHYSICAL PROPERTIES.		
Specific gravity, dried at 212° F., 78° F./78° F.	1.002	1.006[1]
Flashes, ° F., N. Y. State oil-tester	354° F.	376° F.[2]
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	5.9%	3.2%[3]
Character of residue	smooth	smooth
Penetration of residue at 78° F.	soft	soft
Loss, 400° F., 7 hours (fresh sample)	16.7%	17.3%
Character of residue	smooth	smooth
Penetration of residue at 78° F.	soft	soft
Bitumen soluble in CS_2, air temperature	99.9%	99.7%
Difference	.1	.3
Inorganic or mineral matter	.0	.0
	100.0	100.0
Bitumen insoluble in 88° naphtha, air temperature, pitch	7.6%	7.7%
Per cent of soluble bitumen removed by H_2SO_4	48.3	54.9
Per cent of total bitumen as saturated hydrocarbons	47.9	41.9
Per cent of solid paraffines	.0	.0
Fixed carbon	6.0	6.0

[1] Extremes 1.018–.993

[2] Extremes 430°–350°.

[3] Extremes 5.50–.83.

is found to be of the same consistency but much larger in amount than that obtained by the industrial process. It is further not, moreover, surprising that cracking should take place very readily with California petroleums, since it is known that they are composed of the unstable polycyclic polymethylenes of a high degree of molecular aggregation.[1]

In California flux, therefore, we have one which is of a much greater density than that derived from paraffine petroleum, or even that derived from Beaumont, Texas, asphaltic oil. It originates in an unstable petroleum and has been subjected to very severe treatment, and is, therefore, partially cracked. This is apparent in some of the determinations given in the preceding table, where the amount of oils volatile in seven hours at 400° F. is found to be much larger than would be the case with a standard paraffine residuum under similar treatment. This loss, about 17 per cent, must be due to the volatilization of light oils produced by cracking.

Of the components of these California fluxes only 40 to 50 per cent consist of saturated hydrocarbons as compared to 70 or 80 per cent found in paraffine residuum. This points with great probability to the conclusion that such fluxes will harden with age and exposure much more rapidly than the more stable paraffine fluxes.

It will be noted that the residue after heating the California flux to 400° F. is still soft. This is a property which is absolutely essential and differentiates these fluxes from the natural malthas, which, as has appeared, usually become converted into hard pitches on heating for any length of time to a high temperature, and it is this property which makes it possible to use the modern California residuums as a flux.

The fixed carbon which the California residuums yield on ignition is larger than that found in the paraffine residuum, as would be expected from the character of the hydrocarbons of which it is composed, those in the California oil containing a very considerably larger percentage of carbon than those found in the eastern residuums.

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[1] J. Soc. Chem. Ind., 1900, **19**, 123.

In drawing specifications for a California asphaltic flux it should be provided that it should remain soft after heating for seven hours at 400° F. The specifications which the author has proposed for use in work under his directions on the Pacific slope are as follows:

Specifications for "G" Grade California Flux.—"California flux, known as 'G' Grade Flux, should be a residue from the distillation of California petroleum, with steam agitation, at a temperature not above 620° F.

"It shall have the following characteristics:

"It shall be soluble in carbon disulphide to the extent of 99 per cent and in 88° naphtha to the extent of 90 per cent.

"It shall be free from water, shall not flash below 350° F. in a New York State oil-tester, and shall have a density of not less than .98, 12.9° B., or more than 1.050, 9.3° B., at 25° C. when referred to water at the same temperature.

"It shall volatilize not more than 5 per cent of oil when heated for seven hours at 325° F., according to the method employed in the New York Testing Laboratory.

"The residue from heating the oil in the same way to 400° F. for seven hours shall be a soft flux not hard enough to give a penetration of less than 150° with the Bowen penetration machine.

"It shall not yield more than 6 per cent of fixed carbon on ignition. Under the microscope, beneath a cover-glass, it shall appear free from insoluble or suspended matter."

One of the most important characteristics of a California flux to be noted from an industrial point of view is that, owing to its great density, more than twice as much of it is required to soften the solid native bitumens as of a paraffine residuum or of one of the semi-asphaltic nature produced from Texas oil. For example, with Trinidad asphalt 51 pounds of a California flux are often necessary to make a cement of normal penetration where no more than 22 pounds of paraffine residuum are used.

The disadvantages to be met with in the use of a California flux or the defects in its character have been presented in the preceding paragraphs. Aside from this the flux presents certain advantages and desirable properties which cannot be equalled in any other softening agent, and on this account makes it of great value in certain problems in the paving industry. With an asphalt such as that from La Patera, California, or the Bejucal mine in Cuba, a satisfactory paving material could not be made were it not possible to supply the deficiencies of malthenes in these hard bitumens by means of those present in a California flux. The use of the material in this way was well illustrated in the Alcatraz XX asphalt, which was formerly on the market. Sixty per cent of La Patera asphalt was mixed with 40 per cent of dense California residuum and the resulting product was a bitumen which contained asphaltenes and malthenes in normal proportions, and which, when made with care and uniformity, proved a desirable material. Great uniformity in its manufacture was not possible, however, and the defects inherent therein will be considered when the study of asphalt cements is taken up.

As in the case of paraffine residuums, so with the California fluxes: in the early days of the industry they were not at all carefully prepared, and even to-day many of them are found on the market which are too badly cracked to be desirable. They can, with care, however, be prepared with a very considerable degree of uniformity, as can be seen from the extremes given in the table on page 137.

As an example of an unsatisfactory flux the following will serve:

TEST NO. 69012.

Specific gravity, 78° F./78° F.	.9815
Loss, 212° F.	.8%
" 325° F., 7 hours	8.0
" 400° F. " " (fresh sample)	16.2
Penetration of 400° F. residue	43°
Bitumen insoluble in 88° naphtha, air temp.	9.0%
Fixed carbon	6.0

In this flux the specific gravity is low, with the result that there is a large loss of volatile matter at 325° F., while the residue after heating to 400° F. is a solid bitumen, showing that the flux is not a stable one and therefore undesirable.

Fluxes from Beaumont and Similar Oils.—Petroleum of the character of that found in the well-known Beaumont field in Texas is usually considered to have an asphaltic base, but, as is not so well known, it also contains a very considerable proportion of paraffine hydrocarbons, or hydrocarbons which are extremely stable, as shown by their behavior with sulphuric acid,[1] the loss on treatment of the crude oil with sulphuric acid being only 39 per cent as compared with 30 per cent for an Ohio oil and a still larger amount for the asphaltic petroleums of California. The result is that the residuum or flux prepared from Beaumont petroleum possesses some very desirable properties, as revealed by the following determinations:

BEAUMONT, TEXAS, FLUX.

Test number	69330	66364
Quality	light	heavy
PHYSICAL PROPERTIES.		
Specific gravity, dried at 212° F., 78° F./78° F.	.9565	.9735
Flashes, ° F., N. Y. State oil-tester	395° F	418° F.
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	4.3%	.8%
Character of residue	smooth	smooth
Penetration of residue at 78° F.	soft	soft
Loss, 400° F., 7 hours (fresh sample)	14.5%	6.2%
Character of residue	smooth	smooth
Penetration of residue at 78° F.	soft	soft
Bitumen soluble in CS$_2$, air temperature	99.8%	99.6%
Difference	.2	.4
Inorganic or mineral matter	.0	.0
	100.0	100.0
Bitumen insoluble in 88° naphtha, air temperature, pitch	2.5%	4.8%
Per cent of soluble bitumen removed by H$_2$SO$_4$	25.4	20.9
Per cent of total bitumen as saturated hydrocarbons	72.8	79.4
Per cent of solid paraffines	1.0	1.7
Fixed carbon	3.0	3.5

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[1] J. Soc. Chem. Ind., 1901, 20, 690.

When the preceding results are compared with those which have been given as representing the character of the paraffine residuums and of California fluxes, it will be seen that the density of these oils is much higher than that of the true paraffine residuums, but much lower than that of the California fluxes, and that the percentage of total bitumen which is present as saturated hydrocarbons is between 70 and 80 per cent as compared to 40 and 50 per cent in the latter form of flux. This must be a very desirable property and one which is due probably to the presence of an appreciable amount of paraffine hydrocarbons and of a large proportion of stable polymethylenes. The investigations of Mabery and the author have shown that the polymethylenes belong to the C_nH_{2n}, C_nH_{2n-2}, and C_nH_{2n-4} series. That paraffine hydrocarbons are present, and that some of them are of high molecular weight, is revealed by the fact that the residuum contains 1 per cent of paraffine scale. As prepared for use as a flux the residuum is much denser than ordinary paraffine flux, its specific gravity being .95 to .96 as compared with .93 for the latter. In other respects, when very carefully prepared, it is not essentially different in its physical properties. It sometimes contains a slightly larger proportion of light oils, volatile at 325° F., but the same proportions of the lighter flux and hard asphalt are necessary as in the case of paraffine residuum. The denser form, with a gravity of .97, is only used with asphalts that are deficient in malthenes, such as Trinidad land asphalt.

The above conclusions only hold true when the residuum is carefully prepared and some is found on the market which, like the less carefully distilled paraffine residuum of the earlier years of the industry, is not satisfactory. If carefully prepared, however, it is without doubt the most desirable flux which is available to-day for the purpose for which it is used.

Specifications for this residuum may read as follows:

"This oil or flux shall consist of the heavier or higher boiling hydrocarbons of Texas oil containing not more than 3 per cent of paraffine scale, as determined according to the method described in "The Modern Asphalt Pavement," John Wiley & Sons. It shall be of a character suitable for fluxing grahamite and other hard bitumens in such a way that, when forty (40) parts of grahamite and sixty (60) parts of the flux are melted together at 400° F., the resulting product shall not, after 24 hours in an ice box, contain free oil or have a granular or short structure, due to the presence of paraffine. It shall have a gravity not less than .97 at 78° F., shall not volatilize more than five per cent when heated at 400° F. for seven (7) hours, and shall not flash below 400° F. in a closed oil tester, New York State pattern.

"It shall be free from water and decomposition products, contain not more than 3% of bitumen insoluble in 88° naphtha, and shall not volatilize more than 5 per cent when heated for seven (7) hours at a temperature of 325° F."

As has already been said, the supply of flux of this description is nearly exhausted at the present time, owing to the decline of the Beaumont field and the mixing of petroleums from various fields in pipe lines, many of which contain a large proportion of paraffine oil.

Other Fluxes.—While the fluxes which have been previously described are those which are actually in use in the industry in the United States, others are found on the Continent of Europe which, although not available for use in this country, would be entirely satisfactory if this were the case. Among these may be mentioned residuum from the distillation of Russian petroleum. This is free from paraffine scale and consists of very stable hydrocarbons, and with it an especially desirable asphalt cement could be made, if it were reduced to a proper density and uniformity.

In France residuum from the distillation of shale oils is available and is largely used in the fluxing of asphalts for use in mastic. Such an oil has the properties shown in table on page 144.

It will be noticed that this oil consists very largely of unstable hydrocarbons, as would be expected in one which is the product of the distillation of shales, a process in which cracking must go on to a certain extent, and contains a very considerable quantity of paraffine scale.

Wax Tailings.—Wax tailings, or still wax, is a thick, yellow-brown buttery product at ordinary temperature, which melts to a thin liquid at about 175° F. It is the product of the destruc-

SHALE-OIL RESIDUUM FROM FRANCE. GOUDRON DE SCHISTE D'AUTUN.

Test number	65402	72630
PHYSICAL PROPERTIES		
Specific gravity, dried at 212° F., 78° F./78° F.	.9849	.9894
Flashes, ° F., N. Y. State oil-tester	215° F	355° F.
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	7.6%	5.0%
Character of residue	soft	soft
Loss, 400° F., 7 hours (fresh sample)	26.4%	10.0%
Character of residue	soft	soft
Bitumen soluble in CS_2, air temperature	99.7%	99.8%
Difference	.3	.2
Inorganic or mineral matter	.0	trace
	100.0	100.0
Bitumen insoluble in 88° naphtha, air temperature, pitch	6.4%	7.3%
Per cent of soluble bitumen removed by H_2SO_4	53.5	56.2
Per cent of total bitumen as saturated hydrocarbons	43.6	43.5
Per cent of solid paraffine	4.4	5.2
Fixed carbon	3.0	5.0

tive distillation of paraffine petroleum residuum, the residue in the still being coked.

Owing to the method of preparation the product found on the market is extremely variable in character. The results of the examination of several lots in the author's laboratory are given in the table on p. 145.

It appears from the data given that, as has been said, wax tailings are extremely variable in character. They often carry a large amount of water and vary in specific gravity and flash point. Usually they contain but little volatile oil, although on heating at 400° F. they become converted, as a rule, into a solid substance of various degrees of consistency. Wax tailings are almost absolutely pure bitumen, and it is surprising to find that, although they are the result of destructive distillation they

WAX TAILINGS.

Test number	30245	55285	64439	64587	64916
Original material:					
Loss, 212° F., until dry	7.0%	....	....	2.8%[1]	15.5%[1]
" 325° F., 7 hours	....	16.2%[1]			
Residue—pen. at 78° F	....	58°			
Dry material:					
Specific gravity 78° F./78° F.	1.02	1.0794	....	1.1445	1.0994
Flashes, ° F.	298° F.	240° F.	....	340° F.	410° F.
Loss, 325° F., 7 hours	5.9%	....	....	3.0%	2.1%
Residue—pen at 78° F.	83°	....	....	58°	soft
Loss, 400° F., 7 hours (fresh sample)	13.3%	....	....	4.8%	4.6%
Residue.—pen. at 78° F.	brittle	....	....	9°	50°
Bitumen soluble in CS_2	99.9%[2]	....	....	99.8%	99.8%
Difference	....	....	....	.2	.2
Inorganic or mineral matter	....	....	....	.0	.0
				100.0	100.0
Bitumen sol. in 88° naphtha	83.1%	....	97.2%	96.7%	98.1%
This is per cent of total bitumen	....	....	....	96.9	98.4
Bitumen sol. in 62° naphtha	....	....	....	98.9%	99.6%
This is per cent of total bitumen	....	....	....	99.1	99.7
88° naphtha sol. bitumen:					
Per cent not removed by H_2SO_4	....	....	49.3%	50.0%	55.0%
Unacted on by H_2SO_4,SO_3	3.7%	....	0.4	1.1	2.3
Paraffine scale	....				
Fixed carbon	5.5	....	....	4.1	3.4
Bitumen insoluble in cold carbon tetrachloride	....	....	....	0.0	0.0

[1] Contains a large amount of water.

[2] Unacted on by H_2SO_4, 79.9%.

contain 50 per cent of saturated hydrocarbons unacted upon by strong sulphuric acid, although fuming sulphuric acid destroys them entirely. Although produced from a residuum carrying considerable paraffine scale, mere traces of this material are found in the tailings. The amount of fixed carbon which they yield is low, as would be expected in the case of a substance derived from paraffine petroleum. Wax tailings, owing to the lack of uniformity in the material, are of no interest in the paving industry, but are used to a very considerable extent in insulating and other bituminous compounds.

SUMMARY.

From the preceding data it appears that there are three classes of fluxes available commercially in the United States for the softening of native solid bitumens in the preparation of asphalt cement for paving purposes: paraffine residuums, asphaltic residuums of California, and the semi-asphaltic residuums of Texas, and from the Oklahoma and Kansas fields, the Texas being the most desirable of all and probably sufficiently superior to the good paraffine residuums to justify an additional expenditure for its use in work of the highest grade, the reasons for which have appeared in the preceding pages.

The standard residuums from paraffine oil will, however, continue to be used over a large area of country where they can be obtained at considerably lower prices than other fluxes and where the conditions to be met are such that they are entirely satisfactory.

CHAPTER IX.

THE SOLID BITUMENS.

WITH the solid bitumens, consisting largely of paraffine hydrocarbons, such as ozocerite, hatchettite, etc., the paving industry has nothing to do, nor is it interested in the terpenes, fossil resins, amber, etc., which are composed largely of unsaturated cyclic compounds. Our attention must be at once turned, therefore, to the solid bitumens which are of commercial importance in the paving industry, especially the asphalts.

The Asphalts.—The asphalts industrially include all the solid native bitumens which are in use in the paving and other industries. Specifically, true asphalt is sharply differentiated from several of the bitumens which are used under this designation, such as gilsonite and grahamite. In the table which follows the physical properties and proximate composition of the more prominent asphalts, using the term in its industrial sense, which are or have been used in the paving industry, are given.

Until recently but little has been known of the nature of asphalt beyond the fact that it is a native bitumen. Boussingault's investigation of the viscid bitumen and asphalt of Pechelbron, so often quoted, threw no light on the question from the point of view of modern chemistry, as he merely separated the material into two portions, one more volatile than the other, and both, without doubt, more or less decomposed by the heat to which they were subjected, and consisting of mixtures of various hydrocarbons and their derivatives. Warren, who revised the subject of the hydrocarbons for Dana's Mineralogy, states that the following "classes of ingredients" are present in asphalt (see page 150):

PHYSICAL PROPERTIES AND PROXIMATE

Test number	63260	36721
Bitumen	Trinidad lake refined.	Trinidad land refined.
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F. Original substance, dry	1.40	1.4193
Color of powder or streak	Blue black	Brown black
Lustre	Dull	Dull
Structure	Homogeneous	Homogeneous
Fracture	Semi-conchoidal	Semi-conchoidal
Hardness, original substance	2	2
Odor	Asphaltic	Asphaltic
Softens	180° F.	188° F.
Flows	190° F.	198° F.
Penetration at 78° F.	7°	0°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	1.1%	1.0%
Character of residue	Smooth	Blistered
Loss, 400° F., 7 hours (fresh sample)	4.0%	3.0%
Character of residue	Blistered	Blistered
Bitumen soluble in CS_2, air temperature	56.53%	54.1%
Inorganic or mineral matter	36.50	38.0
Difference	6.97	7.9
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	35.6%	33.5%
This is per cent of total bitumen	63.1	61.9
Per cent of soluble bitumen removed by H_2SO_4	61.3	64.8
Per cent of total bitumen as saturated hydrocarbons	24.4	21.8
Bitumen soluble in 62° naphtha	41.7%	38.2%
This is per cent of total bitumen	73.9	70.6
Carbenes:		
Bitumen insoluble in carbon tetrachloride, air temperature	.....	0.0%
Bitumen more soluble in carbon tetrachloride, air temperature	1.3%	.....
Bitumen yields on ignition:		
Fixed carbon	10.8%	12.9%
Sulphur	6.2%	5.0%

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[1] These bitumens are not strictly asphalts, as appears in the text, but may

COMPOSITION OF THE MORE IMPORTANT ASPHALTS.

44412 Bermudez refined, 1900	67753 Bermudez refined, 1903	22220 Cuban, Bejucal.[1]	13541 Califorina, La Patera.	13601 California, Standard.[1]	66923 Maracaibo.
1.0823	1.0575	1.305	1.3808	1.0627	1.0638
Black	Black	Red-brown	Black	Black	Black
Bright	Bright	Dull	Dull	Dull	Bright
Uniform	Uniform	Compact	Uniform	Uniform	Uniform
Semi-conchoidal	Semi-conchoidal	Semi-conchoidal	Irregular	Semi-conchoidal	Semi-conchoidal
Soft	Soft	2	2	Soft	Soft
Asphaltic	Asphaltic	Asphaltic	Asphaltic	Asphaltic	Asphaltic
170° F.	160° F.	230° F.	260° F.	170° F.	200° F.
180° F.	170° F.	240° F.	300° F.	180° F.	210° F.
22°	26°	0°	0°	0°–27°	20°
3.0%	4.4%	.88%	1.5%	6.6%	2.7%
Smooth	Smooth	Cracked	Shrunken	Smooth	Blistered
8.2%	9.5%	1.5%	2.5%	19.9%	4.7%
Wrinkled	Shrunken	Wrinkled	Shrunken	Blistered	Much blist.
95.0%	96.0%	75.1%	49.3%	89.8%	96.8%
2.5	2.0	21.4	48.6	6.8	1.8
2.5	2.0	3.5	2.1	3.4	1.4
100.0	100.0	100.0	100.0	100.0	100.0
62.2%	69.1%	32.4%	21.6%	53.4%	45.7%
65.4	71.9	43.1	43.8	59.4	47.2
62.4	67.3	60.5	81.4	51.9	46.4
24.4	23.4	17.0	8.1	28.6	25.3
69.2%	75.9%	39.6%	26.7%	60.0%	51.5%
72.8	79.0	52.7	54.1	66.8	53.2
0.1%	1.1%	....	....	0.3%	17.5%
....	....	1.6%	1.7%		
13.4%	14.0%	25.0%	14.9%	8.0%	18.0%
4.0%	....	8.3%	6.2%		

be considered as such in their relation to the asphalt paving industry.

WARREN'S CHARACTERIZATION OF ASPHALTUM.[1]

"A. Oils vaporizable at or about 100° or below; sparingly present if at all.

"B. Heavy oils, probably of the Pittolium or Petrolene groups; vaporizable between 100° and 250°, constituting sometimes 85 per cent of the mass.

"C. Resins soluble in alcohol.

"D. Solid asphalt-like substance or substances, soluble in ether and not in alcohol; black, pitch-like, lustrous in fracture; 15 to 85 per cent.

"E. Black or brownish substance or substances, not soluble in either alcohol or ether; similar to D in color and appearance (Kersten); brown and ulmin-like (Völckel); 1 to 75 per cent.

"F. Nitrogenous substances; often as much as corresponds to 1 or 2 per cent of nitrogen."

He also defines asphalt as "a mixture of different hydrocarbons parts of which are oxygenated."

In the light of our present information neither the classification of the proximate constituents nor the definition of asphalt is satisfactory.

A. Hard asphalts and but few malthas seldom contain any oils vaporizable at 100°. Such hydrocarbons cannot be present in any amount in a hard asphalt, as the material would then have the properties of a maltha.

B. Heavy oils are undoubtedly the chief constituents of asphalt and as such require the most careful study and differentiation to determine their nature. Recent investigations have shown that these oils are a mixture of saturated and unsaturated hydrocarbons of di- and polycyclic series and of their sulphur and nitrogen derivatives, the sulphur derivatives being particularly characteristic of asphalt. This class of oils is that which we name to-day malthenes.

C. Resins are not present in asphalt. The oils are slightly soluble in alcohol, but the soluble portion is not similar to resin in its behavior towards reagents.

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[1] Descriptive Mineralogy, Dana, 6th Edition, 1896, 1017.

D. The substances soluble in ether are soft and resemble malthas. They are the same substances mentioned under B. They usually amount to from 60 to 75 per cent of the asphalt.

E. The bitumen not soluble in ether (petroleum naphtha is now commonly used instead of ether as a solvent) is a hard substance which does not melt without decomposition but is soluble in the malthenes, the predominating constituent of asphalt, or in heavy asphaltic oils. Together with the malthenes it constitutes the pure bitumen of asphalts. It contains the larger part of the sulphur compounds present and seems to owe its hardness to this fact. It is known as asphaltenes.

F. Nitrogenous substances are found both in the malthenes and in the hard bitumens of class E. In the malthenes the nitrogen derivatives have been identified as hydrocyclic bases.

As has already been said, there is a decided difference in the use of the term asphalt in an industrial and specific sense.

From investigations carried on in the author's laboratory within the last seven years, the results of which have been largely published elsewhere,[1] it is possible to characterize true asphalt more closely and to differentiate it specifically from other solid bitumens.

Asphalt may be defined, industrially, as a mineral pitch, found in nature in a more or less solid state, melting at a temperature in the neighborhood of that of boiling water, and miscible in all proportions with heavy petroleum oils or fluxes to form a viscous cementing material which is in use in the paving and in other industries.

More specifically asphalt is a bitumen found in nature, originating in certain types of petroleum, of various degrees of consistency, but generally solid, softening at a temperature in the neighborhood of 100 degrees Centigrade, and consisting of a mixture of various saturated and unsaturated hydrocarbons and their derivatives, a part of which are soluble in naphtha, very viscous liquids, largely saturated hydrocarbons unattacked by strong sulphuric acid in such a solvent; while those insoluble in naphtha are soluble in carbon disulphide and carbon tetrachloride, brittle solids which do not melt by themselves without decomposition on the application of heat.

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[1] On the Nature and Origin of Asphalt, Long Island City, N. Y., 1898.

The naphtha soluble bitumen is known, conventionally, as a class, as "Malthenes," while the bitumen insoluble in naphtha, but soluble in carbon disulphide, has been called "Asphaltenes." The malthenes consist in part, depending upon the hardness of the bitumen, of from 20 to 50 per cent of saturated di- or polycyclic polymethylenes of the series of C_nH_{2n-2}, C_nH_{2n-4}, C_nH_{2n-8}, etc., the lowest member found in Trinidad asphalt being $C_{13}H_{24}$ boiling at 165° C. under a pressure of 30 mm.; in part of unsaturated hydrocarbons, which can be separated from the polymethylenes by strong sulphuric acid with which they combine readily, the nature of which is not so well understood; of sulphur compounds separated in the same way which, on isolation, are found to be the same as those occurring in Ohio, Canadian, and California petroleum and nitrogen derivatives, perhaps bearing the same relation to the polymethylenes that chinolin does to benzol. The structure of these saturated hydrocarbons is given on page 105. The asphaltenes are probably unsaturated hydrocarbons or their derivatives, as they are all strongly acted upon by concentrated sulphuric acid. The molecules of which they consist must be highly condensed and have a very high molecular weight. Of their structure we know nothing. The asphaltenes contain the greater part of the sulphur present in asphalts, and they are, as a rule, characterized by the presence of very considerable amounts of it, the larger the amount the harder the asphalt.[1] Normal asphalts yield about from 10 to 15 per cent of fixed carbon on ignition, a fact which enables us to differentiate them by this characteristic alone from many of the other solid bitumens.

Differentiation of the Asphalts among Themselves.—Considered as pure bitumens, the asphalts vary quite largely in character among themselves, depending upon the nature of the bitumen from which they have been derived, the extent to which they have been metamorphosed by their environment, and the resulting difference in the relative proportions of malthenes and asphaltenes, and of saturated and unsaturated hydrocarbons which are present. Those asphalts which have undergone the most complete metamorphism contain the largest portion of the asphaltenes and are the harder. A high percentage of sulphur also works in the same direction. Some actual variations in the amount of the total bitumen soluble in cold 88° naphtha in asphalts of different degrees of hardness are as follows:

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[1] On the Nature and Origin of Asphalt, Long Island City, N. Y., 1898.

No. 22220.	Hard asphalt, Bejucal, Cuba.	43.1%
" 13541.	" " La Patera, Cal.	43.8
——	Medium hard, Trinidad.	65.0
——	Softer asphalt, Bermudez.	69.0

The following differences have been noted in the amount of sulphur found in the pure bitumen from the same localities:

No. 13541.	La Patera, Cal.	6.20%
" 22220.	Cuban, Bejucal	8.28
" 63260.	Trinidad Lake.	6.16
" 44412.	Venezuela, Bermudez.	3.93

The asphalts can also be differentiated by their physical properties, such as consistency, which is particularly valuable, by their melting-point, color, and specific gravity, though in the form of pure bitumen they are not very variable in the latter respect, and by other minor differences.

Asphalt Associated with Mineral Matter.—In the preceding paragraphs, asphalt has been considered as a more or less pure bitumen, but it is more often than not associated with mineral matter of one kind or another. This fact has resulted in a classification of this material on this ground alone, according to the nature of the mineral matter. Such a classification may be of some industrial value, although having nothing to do with the character of the asphalt itself. At best it is artificial. The following, based on the writer's investigation of a large number of asphalts from all over the world, is suggested:

Asphalt.—1. Impregnating compact, amorphous limestones to the extent of less than 16 per cent.

2. Impregnating limestones, partially crystalline and mixed with silica or silicates, to the same extent.

3. Impregnating fossiliferous limestones to the same extent.
4. Impregnating shales or schists.
5. Impregnating hard sandstones.
6. Mixed with silica and clay to a fixed and uniform extent at the source where the asphalt originates.
7. Mixed with sands by percolation into beds of the latter in place.
8. Mixed with soil and organic matter of vegetable origin where the effusion of tar springs have hardened on exposure.

Type 1 is found on the continent of Europe, in Sicily, Val de Travers, Seyssel, and in the United States but to a limited extent in Utah.

Type 2 is found in Oklahoma, near Ravia and elsewhere.

Type 3 occurs near Dougherty in Oklahoma, the rock being a member of the lower coal measures, according to Eldridge, and in the neighboring Buckhorn District.

Type 4 is found in Ventura County, California.

Type 5 is found in the same locality.

Type 6 is unique, Trinidad Lake Asphalt.

Type 7 includes large deposits of sand in Kentucky and California, which are saturated, in situ, with a rather soft asphalt.

Type 8 is found wherever exudations of bitumen have spread over the soil and become hardened by exposure. They are common in Kern County, California.

It appears, therefore, that the character of the mineral matter, with which an asphalt is mixed naturally, must be considered as well as the nature of the bitumen itself, in forming an opinion of its availability for paving purposes.

With the information which has been presented in the preceding pages it is now possible to consider individually each of the native bitumens, known generically or specifically as asphalts, and afterwards to make a comparative study of their availability in the paving industry.

SUMMARY.

Asphalt is a term which may be used either industrially or specifically; industrially to cover all the solid native bitumens used in the paving industry and specifically to include only such as melt on the application of heat, at about the temperature of boiling water, are equally soluble in carbon disulphide and carbon tetrachloride and to a large extent in 88° naphtha, those hydrocarbons soluble in naphtha consisting to a very considerable degree of saturated hydrocarbons, yielding about 15 per cent of fixed carbon and containing a high percentage of sulphur. Under this definition it can be seen that grahamite is not an asphalt, since it is not largely soluble in naphtha and yields a very high percentage of fixed carbon on ignition. It is also less soluble in carbon tetrachloride than in carbon disulphide. Gilsonite is not an asphalt, since the saturated hydrocarbons contained in the naphtha solution are very small in amount and quite different in character from those found in asphalt.

CHAPTER X.

INDIVIDUAL ASPHALTS.

Trinidad Lake Asphalt.—In considering the asphalts individually, it will be best to examine in detail the characteristics of the one in regard to which the most is known and with which the most successful pavements have been laid and then to compare others with it. Trinidad lake asphalt is, of course, the one referred to. The location of the deposit and the manner of its occurrence may be summarized as follows:[1]

"The island of Trinidad lies off the north coast of South America, between 10° and 11° of latitude and 61° and 62° of longitude (Fig. 4). It is bounded on the north by the Caribbean Sea, on the east by the Atlantic, on the south by a narrow channel, into which flow the waters of the northern and most westerly mouths of the Orinoco, and on the west by the Gulf of Paria, the two latter bodies of water separating it from the mainland of Venezuela. . . .

"While there are deposits of pitch scattered all over the island, the only ones of commercial importance are those situated on La Brea Point, in the wards of La Brea and Guapo, in the county of St. Patrick, on the western shore of the island. They are about 28 miles in an air line from Port of Spain, the seat of government, the chief harbor and only port of entrance, and lie on the north shore of the southwestern peninsula, the point upon which they are situated being apparently preserved from destruction by the sea, which is elsewhere rapidly wearing away the coast by the bituminous deposits which exist along the shore and even some distance from it, and which from their toughness resist the action of the waves better than the soft rocks of this region. The pitch deposits are found scattered over the point, but can be divided conveniently into two classes, according to their source.

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[1] Report of the Inspector of Asphalt and Cements, Eng. Dept., District of Columbia, 1892. On the Nature and Origin of Asphalt, Long Island City, N. Y., 1898.

"The main deposit is a body of pitch known as the Pitch Lake, situated at the highest part of the point.

"Between this and the sea, and more especially toward La Brea, are other deposits, covered more or less and mixed with soil.

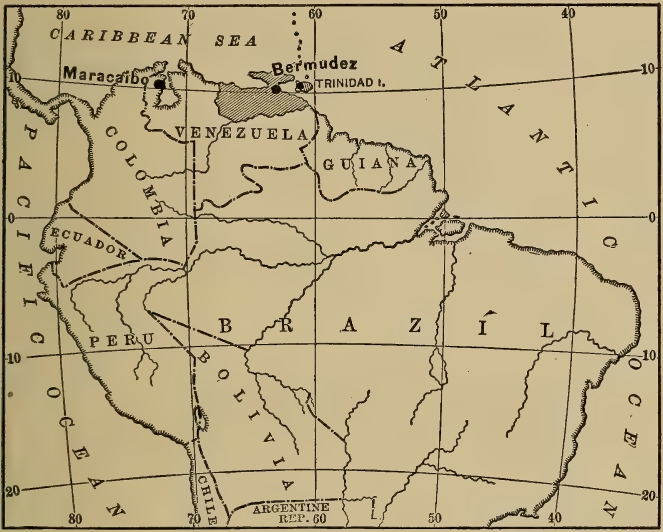

FIG. 4.

"The pitch from these sources is classed as 'lake pitch' and 'land pitch.'

"By far the largest amount of pitch is found in the pitch lake, originally nearly a circular area of 127 acres, the surface of which, in 1894, was 138.5 feet above sea level. From the lake the ground falls away on all sides, except, perhaps, a slight ridge to the east and southeast. In fact it seems plain that this deposit lies in the crater of a large mud volcano which has filled up with pitch."

It appeared, when first examined by the author in 1891, "as a flat, gently sloping mound, wooded over a large portion, open savanna elsewhere, and toward the northeast merely grassed over.

"On the west its slopes toward the sea are gentle for some distance, but then more abrupt. On the north, toward La Brea Point, the reverse is the case, and a ravine runs, with a small stream, quite to the village, this slope being very scantily covered by a growth of coarse grass near the lake, becoming more bushy farther on, while the other slopes are well wooded, with magnificient palms near the lake, forming a beautiful band or border around it, within which is a grassy zone of about 100 to 200 feet or more in width."

Since then the removal of large quantities of pitch has quite changed the surroundings, owing to the cutting off of the wood and other alterations resulting from the operations incident to the exportation of asphalt.

In 1893 a series of borings were made upon the lake by the New Trinidad Lake Asphalt Company.

"A boring at the center of the lake was carried to a depth of 135 feet, the entire distance being through pitch, which, as far as ocular evidence goes, has the same character as that at the surface. It was impossible to carry the boring deeper, as the movement of the pitch had so inclined the tube—one foot in six—which formed the lining, that it had to be abandoned. It then gradually toppled over and was engulfed. Nothing has been seen of it since. The result was sufficient, however, to show the great depth of the crater and the uniformity of the pitch. The depth attained was within a few feet—not more than three and a half—of sea level, and yet we do not know how much deeper the pitch may extend. The borings on the north side of the lake about 1000 feet from the centre, and 100 feet from the edge, was in pitch of the usual character for 75 feet, showing a very steep slope to the sides of the crater. At 80 feet a layer of fine white sand was met for a few feet, and then asphalt was again encountered. At 90 feet sand mixed with asphalt was struck, and this continued to a depth of 150 feet.

"Further borings, made at some distance from the lake, gave results near the surface which were similar to those found at the deeper levels at the edge of the lake. Sand, mixed with asphalt here and there, was the common material, while at a depth of

80 feet on the southern side of the lake, and about 80 feet south of the road, and between 1200 and 1300 feet from the centre of the lake, a very hard asphaltic sandstone was found.

"All the evidence thus goes to show that the sides of the crater are of sand or sandstone, more or less impregnated with bitumen, the sandstone being no doubt the rock of the hillside toward the south, against which the crater has been built up.

"From the borings it was thus learned for the first time how enormous the deposit was, and the idea that the mound was really a crater seemed to be confirmed. It is, nevertheless, hard to realize that there is at this point, 138 feet above the sea, a bowl-like depression over 2300 feet across, and over 135 feet deep, reaching below the sea level, and filled with a uniform mass of pitch, which must amount to over 9,000,000 tons."

Crude Trinidad asphalt is an extremely uniform mixture or emulsion of gas, water, fine sand, clay and bitumen which are found in the following proportions:

Bitumen	39.3%
Mineral matter	27.2
Water of hydration of clay	3.3
Water and gas, loss at 325° F.	29.0
	98.8%

The material is of the greatest uniformity in composition, as it has been found that specimens collected at intervals of 100 feet and at a depth of 1 foot over the surface of the deposit and to a depth of 135 feet at the centre all have the same composition as appears from the following table.

The amount of uncombined water does not appear among the constituents in these determinations as, in order to avoid any possibility of change, it was removed by air-drying at the lake in the course of the preparation of the samples for transportation to the United States. Frequent examinations of the crude asphalt in a fresh condition have shown, however, the water to be as constant in amount as the other constituents.

In this deposit there are, therefore, many millions of tons of asphalt of a highly uniform composition, not only as far as the

AVERAGE COMPOSITION OF TRINIDAD LAKE ASPHALT IN CIRCLES.

	Bitumen by CS_2.	Mineral Matter on Ignition.	Difference Undetermined.[2]	Soluble in Naptha.[1]	Total Bitumen thus Soluble.
Circle 2: 200 feet from centre. .	55.02%	35.41%	9.57%	31.83%	57.85%
" 4: 400 " " " . .	54.99	35.40	9.61	31.63	57.55
" 6: 600 " " " . .	54.84	35.49	9.67	31.85	58.26
" 8: 800 " " " . .	54.66	35.56	9.78	31.67	57.97
" 10: 1000 " " " . .	54.78	35.44	9.78	31.58	57.64
" 12: 1100 " " " . .	54.62	35.45	9.93	31.77	57.51
General Average.	54.92	35.46	9.72	31.72	57.79
Circle 14: 1400 feet from centre. .	53.86	36.38	9.76	30.52	56.66

AVERAGE COMPOSITION OF TRINIDAD LAKE PITCH FROM THE BORING.

From surface to 135 feet in depth.	54.66%	35.90%	9.44%	31.53%	57.67%

[1] This naphtha possessed less solvent power than usual.

[2] Water of clay, not lost on refining, bitumen held by clay and inorganic salts, volatilized on ignition.

proportions of bitumen and mineral matter are concerned, but also in the relation of the malthenes to the asphaltenes.

Constitution of Crude Trinidad Asphalt.—The constitution of the material forming the great deposit found in the Pitch Lake in the Island of Trinidad has only been explained very recently. In the course of the ordinary routine analysis of the substance from which the water has been removed, it is found that the summation of the percentages of bitumen soluble in cold carbon disulphide and of the mineral matter obtained by ignition does not amount to 100, as is seen in the above table. It has been the custom for many years to call the difference between this sum and 100 "organic matter not bitumen." Recent investigations of the author [1] have shown that this is an entirely incorrect statement, as the asphalt contains practically no organic matter not bitumen, and that the undetermined matter or difference can be readily explained as follows:

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[1] The Proximate Composition and Physical Structure of Trinidad Asphalt, Proc. Am. Soc. Test. Materials, 1906, 6, 509.

Water and Gas.—If a weighed amount of crude Trinidad asphalt, immediately after being taken from the deposit, is ground to a fine powder and exposed to the air for twenty-four hours, it will lose about 29 per cent of water and a small additional amount on further exposure in vacuo over sulphuric acid, this latter small amount being very probably water of crystallization of the salts which are present. The total loss averages 29 per cent, with but very small variation, in the fresh pitch taken several inches below the surface, although on exposure to the air for some time a very considerable proportion of this amount may be lost, as in the case of storage of the crude material.

At the same time with the water the gas which it contains in solution, consisting of a mixture of carbon dioxide and hydrogen sulphide, is lost. Its percentage must be extremely small by weight.

Having determined the average amount of water in the fresh pitch with some degree of accuracy it will be convenient to conduct the further investigation of the pitch on the dried or refined material.

Mineral Matter.—The residue of mineral matter obtained on the ignition of refined Trinidad asphalt in a muffle averages, as the result of fifteen determinations of representative samples, 36.5 per cent corresponding to 25.9 per cent in the original crude material, with extremes of 36 and 36.8 per cent. As this ignition has taken place at a temperature approaching 800 degrees Centigrade, there is every reason to believe that considerable inorganic matter has been volatilized, as is often found to be the case in the preparation of the ash of vegetable material. In the latter case the addition of tricalcium phosphate prevents such loss and it seemed that this mode of procedure might be applicable to the asphalt. When the latter was ignited in the presence of the phosphate a residue greater by 2 per cent was obtained, 38.5 per cent, and one which more correctly represents the percentage of anhydrous inorganic matter present in the asphalt, showing that 2 per cent is volatilized in the ordinary course of ignition, thus accounting for that amount of the "undetermined matter."

The mineral matter on examination is found by elutriation to consist to a large extent, 30 to 40 per cent, of clay and, of course, its water of hydration, which may be properly regarded as a part of the mineral matter originally present, is lost on ignition. If the residue after the extraction of the asphalt with solvents is heated to a temperature of 340 degrees Centigrade, it loses from 4 to 6 per cent, the determination at such a temperature of course not being one capable of being made with great accuracy. A certain amount of this loss is plainly due to the volatilization or destruction of bitumen held by the clay present, as shown by its condensation on the side of a glass tube in which the heating is conducted, but as this amount, as will appear later, cannot exceed 1 per cent, the loss due to the presence of water in the clay must reach at least 4.5 per cent. The total loss on ignition of bitumen and water in the clay must, however, amount to about 5 per cent and be included in the "undetermined matter." When this per cent is added to the 2 per cent of inorganic matter volatilized at 800 degrees Centigrade, the entire percentage of undetermined matter obtained by the usual method of analysis is accounted for, so that it appears that Trinidad asphalt really contains practically no organic matter not bitumen.

In order to determine whether this assumption is correct, analyses have been made of mixtures of an extremely pure bitumen, gilsonite, with clay and other fine inorganic materials, the mixture being prepared by melting the bitumen, stirring being kept up during cooling, and the cold brittle mixture being then ground to a fine powder in order to obtain a uniform mixture for analysis. The results of an examination of such mixtures by the routine methods are as follows:

	Bitumen soluble in Carbon Disulphide.	Mineral Residue on Ignition.	Undetermined.
Fullers earth, air dried	62.3%	28.8%	8.9%
" " ignited	59.7	34.1	6.2
Brick clay, air dried	72.3	22.9	4.8
" " ignited	77.9	17.9	4.2
Portland cement, ignited	82.6	15.8	1.6
Trinidad mineral residue, ignited	64.4	34.3	1.3

It appears from the preceding results that all the artifical mixtures of bitumen and fine mineral matter apparently contain, as the result of the analyses, a certain amount of undetermined matter or organic matter not bitumen, although from the nature of these mixtures nothing of this kind can be present. The amount varies from 8.9 per cent in the case of the unignited Fullers earth, to 1.3 per cent for the ignited mineral residue of Trinidad asphalt. The larger percentage is due to the presence of water of hydration in the Fullers earth, while the smaller percentage shows that the mineral matter in Trinidad refined asphalt is capable of retaining 1.3 per cent of bitumen, either by absorption, adsorption, or both. Our assumptions in regard to the true composition of Trinidad asphalt are, therefore, correct and its actual composition should be stated as follows:

	Crude Trinidad Asphalt.	Refined Trinidad Asphalt.
Water and gas	29.0%	....
Bitumen soluble in cold carbon disulphide	39.0	56.5%
Bitumen retained by mineral matter	.3	.3
Mineral matter, on ignition with tricalcium phosphate	27.2	38.5
Water of hydration, clay, and silicates	3.3	4.2
	98.8%	99.5%

Refined Trinidad Lake Asphalt.—Refined Trinidad lake asphalt, which is dried with steam and agitated with steam, has the characteristics given in the table on pages 164 and 165.

Refined Trinidad Lake asphalt is of a homogeneous structure and uniform composition except in so far as the percentage of mineral matter and consequently of bitumen may vary, being greater in one sample than another, through sedimentation caused by the lack of agitation during cooling. It possesses none of the emulsion structure seen in the crude material. It has a dull conchoidal fracture, no lustre, a blue-black color in powder and

REFINED TRINIDAD LAKE ASPHALT. (AVERAGE COMPOSITION.)

Test number	63260

PHYSICAL PROPERTIES.

Specific gravity, 78° F./78° F , original substance, dry	1.40
Color of powder	Blue-black
Lustre	Dull
Structure	Homogeneous
Fracture	Semi-conchoidal
Hardness, original substance	2
Odor	Asphaltic
Softens	180° F.
Flows	190° F.
Penetration at 78° F.	7°

CHEMICAL CHARACTERISTICS.

Dry substance:	
Loss, 325° F., 7 hours	1.1%
Character of residue	Smooth
Loss, 400° F., 7 hours (fresh sample)	4.0%
Character of residue	Blistered
Bitumen soluble in CS$_2$, air temperature	56.53%
Difference undetermined	6.97
Inorganic or mineral matter	36.50
	100.00
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	35.6%
This is per cent of total bitumen	63.1
Per cent of soluble bitumen removed by H_2SO_4	61.3
Per cent of total bitumen as saturated hydrocarbons	24.4
Bitumen soluble in 62° naphtha	41.7%
This is per cent of total bitumen	73.9
Carbenes:	
Bitumen more soluble in carbon tetrachloride, air temperature, than in bisulphide of carbon	1.3%
Bitumen yields on ignition:	
Fixed carbon	10.8
Sulphur	6.2

REFINED TRINIDAD LAKE ASPHALT. (EXTREMES IN COMPOSITION.)

PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.370	1.405
Softens	170° F.	180° F.
Flows	180° F.	190° F.
Flow in per cent of average	122%	90%
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	1.0%	1.5%
Loss, 400° F., 7 hours (fresh sample)	4.8%	3.5%
Bitumen soluble in CS_2	54.0%	57.0%
Malthenes:		
Per cent of total bitumen soluble in 88° naphtha, air temperature	63.0	68.0 [1]
Per cent of total bitumen soluble in 62° naphtha	73.0	77.0
Bitumen yields on ignition:		
Fixed carbon	11.0	10.0

[1] Percentage depends upon the character of solvent naptha and method of treatment.

an asphaltic odor. It softens and flows below the temperature of boiling water, but becomes liquid only at much higher temperatures, about 300° F. Its density is high as compared with most other bitumens, 1.40, owing to the mineral matter which it contains.

Refined Trinidad asphalt differs slightly in composition from the crude material, or rather from this material after the removal, without the aid of heat, of the water which it contains, owing to the volatilization, at the higher temperature used in refining, of certain constituents not driven off at the temperature of boiling water.

The Mineral Matter in Trinidad Asphalt.—The mineral matter in Trinidad lake asphalt is as much a fixed constituent of the material as the bitumen. It is not accidental or adventitious as it would then vary in amount. It has evidently become mixed with the bitumen under fixed and invariable conditions at some subterraneous point where the bitumen originates and meets an environment that results in the production of the asphalt itself.

It is in an extremely fine state of subdivision. On sifting the particles are found to be of the size given below:

Passing 200-mesh sieve	.08	mm.	89.8%
“ 100- “ “	.17	“	8.0
“ 80- “ “	.20	“	2.2
			100.0

And on elutriation of the 200-mesh material:

Subsiding in 15 seconds, smaller than	.08	mm.	24.3%
“ “ 1 minute, “ “	.05	“	13.1
“ “ 30 minutes, “ “	.025	“	46.7
After “ “ “ “	.0075	“	15.9
			100.0

Under the microscope it is found to be composed principally of quartz with clay and the residue of the salts from the mineral water originally emulsified with the crude bitumen. The quartz consists of very sharp flakes, Fig. 2, No. 8, and their appearance leads one to believe that it has originally been in solution under enormous pressure in the thermal water, from which it has separated on the release of the pressure or on cooling, and has finally flown into fragments on further reduction of the pressure to that of the atmosphere. The presence of the clay is more difficult to explain. It is sufficient to know from the point of view of the engineer that the mineral matter is extremely fine, is most intimately mixed with the bitumen by nature and is consequently the most perfect form of filler, far exceeding anything which can be artificially mixed with a purer asphalt, and as such a most desirable constituent.

The clay, when it has been freed by treatment with acid from the oxide of iron which colors it the characteristic flesh-pink color of the ash of Trinidad asphalt and which is derived from the iron salts in solution in the thermal water, is a pure white, impalpable powder which amounts to not more than one-third of the entire mineral matter.

The mineral matter also contains constituents, other than the iron, derived from the thermal water, principally sulphates and chlorides of soda, but as the entire amount of salts in the thermal water is less than 2 per cent, these so-called soluble salts can amount to no more than 1 per cent of the refined asphalt and probably much less, as a part is volatilized in refining and a part rendered insoluble. Actual extraction of the refined asphalt when most thoroughly carried out yields only two-tenths of 1 per cent of soluble salts.

The composition of the mineral matter is as follows:

	Soluble in Acid.	Insoluble.	Total.
Silica, SiO_2	....	70.64	70.64
Alumina, Al_2O_3	7.38	9.66	17.04
Ferric oxide, Fe_2O_3 [1]	6.30	1.32	7.62
Lime, CaO	0.46	0.24	0.70
Magnesia, MgO	0.11	0.79	0.90
Soda, Na_2O	1.56	....	1.56
Potassium, K	0.35	....	0.35
Sulphuric oxide, SO_3	0.97	....	0.97
Chlorine, Cl	0.22	....	0.22
	17.35	82.65	100.00

[1] FeO not determined.

Some of the mineral matter is so impalpably fine that it will not separate from a solution of melted or dried Trinidad pitch in any of the usual solvents even after months of standing and many hours' treatment in a centrifugal. It will pass also through the finest filters. It has been thought by Peckham and others, on this account, to be chemically combined with the organic compounds of the asphalt but the author has found that by continued swinging of a solution of the asphalt in carbon disulphide in a centrifugal it can be so far reduced that it amounts to but 2 per cent, and when the bitumen thus purified is dissolved in chloroform or bisulphide of carbon and passed through a biscuit filter all the mineral matter is removed, leaving an absolutely pure bitumen. This is not surprising, since the smaller amount of mineral matter finally removed is a ferruginous clay and could not possibly be combined with the organic matter in a chemical way, although it no doubt is in a state of close physical combination. In this connection the conclusions of Dr. Allerton S. Cushman of the Office of Public Roads of the U. S. Department of Agriculture on the porosity of clay particles is of interest.

The very finest mineral matter which is separated from Trinidad lake asphalt has the following composition:

ANALYSIS OF FINEST MINERAL MATTER.

	Insoluble in HCl.	Soluble.	Total.
SiO_2.	32.36	. . . . .	32.36
Al_2O_3.	6.74	33.64	40.38
Fe_2O_3.	1.40	11.74	13.14
CaO.	.45	3.20	3.65
MgO.	.34	1.40	1.83
K_2O.	. . . . .	1.18	1.18
Na_2O.	. . . . .	.53	.53
SO_3.	. . . . .	7.16	7.16
	41.29	58.85	100.23

The Bitumen of Trinidad Lake Asphalt.—The bitumen of Trinidad lake asphalt amounts to about 56 per cent of the refined material. It is a lustrous black pitch like all pure bitumens. It has a specific gravity of 1.06 to 1.07 and retains in suspension very persistently amounts of the finest mineral matter of the asphalt, it being only possible, as has been shown, to remove this by passing its solution in bisulphide of carbon through a biscuit-filter of the Pasteur type. In this way it can be obtained in an absolutely pure form. In this condition it has the composition given in table on p. 169.

This bitumen is characterized by the large percentage of sulphur which it contains, and the presence of nitrogen. There are apparently no oxygen derivatives present in the pure bitumen, or they occur in very minute amounts, that is to say, they are insoluble in chloroform or carbon disulphide.

It is characterized also by its great stability or lack of liability to change or volatilize at high temperatures. When 20 grams of the materials are heated in a glass crystallizing dish to 325° F., according to the method described in Chapter XXVIII, it loses but 1 per cent, and only 4 per cent when exposed to a temperature of 400° F. for 7 hours.

TOTAL BITUMEN IN TRINIDAD LAKE ASPHALT.

Preparation.	I.	IV.	V.	Average.
Carbon	82.59	81.95	82.44	82.33
Hydrogen	10.74	10.51	10.81	10.69
Sulphur	6.04	6.54	5.90	6.16
Nitrogen	0.51	0.92	1.00	0.81
	99.88	99.92	100.15	99.99

Of the total bitumen about 63 per cent, when the process of extraction is carried out according to the method described in the chapter referred to, is in the form of hydrocarbons of the class known as malthenes, soluble in 88° B. naphtha, having a density of .994. The malthenes are soft and exceedingly sticky, like maltha. When they are treated with strong sulphuric acid, according to the author's method, all but 39 per cent prove to be unsaturated hydrocarbons which readily enter into combination with acid. This means that but 24 to 25 per cent of the total bitumen in the asphalt consists of saturated hydrocarbons. On ignition these malthenes yield 6.3 per cent of fixed carbon. This is about the same percentage that is found for the denser California fluxes and for the lighter natural malthas.

The malthenes can be fractioned in vacuo into hydrocarbons of different boiling-points, and from them can also be obtained the nitrogen and sulphur derivatives corresponding to those found by Mabery in the sulphur petroleums, all of which have been described bv the author elsewhere.[1]

It is sufficient to state here that the saturated hydrocarbon of lowes boiling-point and molecular weight, which has been separated from the malthenes of Trinidad lake asphalt, has the following properties:

Boiling-point at 30 mm.	165° C.
Specific gravity at 25° C.	.8576
Refractive index	1.4650
Carbon	86.85%
Hydrogen	13.34

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[1] On the Nature and Origin of Asphalt, Long Island City, N. Y., 1898.

Such a hydrocarbon would correspond to one of the C_nH_{2n-2} series having the formula $C_{13}H_{24}$, which contains 86.67 per cent of carbon and 13.33 per cent of hydrogen. That this is the formula has been confirmed by determinations of the molecular weight of the substance, and its molecular refraction. Of the constitution of the hydrocarbons of asphalt something has been said in a preceding chapter.

The bitumen of Trinidad asphalt which is insoluble in 88° naphtha is of the class known as the asphaltenes, according to our purely arbitrary classification; the relative proportion of the two forms of bitumen, asphaltenes and malthenes, being dependent upon the nature of the solvent used, so that any information derived from a determination of the percentages of the two classes of hydrocarbons will be purely relative as compared with other bitumens which have been examined by exactly the same methods and with the same solvents. Trinidad asphalt contains a very small amount of bitumen which is soluble in chloroform, carbon tetrachloride, and turpentine, and which is not soluble in carbon disulphide, as shown by Peckham.[1]

The asphaltenes are hard, brittle bitumens which do not melt but only intumesce on heating, and in this respect, as well as in the percentage of fixed carbon which they yield, 25.8 per cent., correspond closely with the softer grahamites. The asphaltenes are soluble in the heavy asphaltic oils.

The ultimate composition of the malthenes and asphaltenes in Trinidad lake asphalt is as follows, as compared with that of the total bitumen previously given:

	Malthenes.	Asphaltenes.	Pure Bitumen.
Carbon	84.6	82.0	82.33
Hydrogen	11.3	7.8	10.69
Sulphur	2.9	10.9	6.16
Nitrogen	.6	....	0.81
	99.4	100.7	99.99

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[1] Am. J. Science, 1896, [4], **151**, 193.

The saturated hydrocarbons in the malthenes have the following composition:

Specific gravity	.976
Carbon	86.40
Hydrogen	12.70
Sulphur	.45
Nitrogen	.07
	99.62

From these figures it appears that the sulphur derivatives are largely contained in the asphaltenes and in but relatively small amounts in the malthenes, while they are almost completely removed from the latter by treatment with strong sulphuric acid. From the ultimate composition of the saturated hydrocarbons contained in the malthenes it is evident that these belong to a series in which the number of hydrogen atoms is considerably below twice the carbon atoms, that is to say, they must be di- or polycyclic polymethylenes, and very similar to those which are found in Texas, California, and other asphaltic oils.

With the aid of the above data some insight may be gained of the character of the bitumen of Trinidad lake asphalt. In other asphalts and solid bitumens the proportion of malthenes to asphaltenes may be greater or less, while the amount of saturated hydrocarbons which they contain may vary. If we accept the bitumen of Trinidad lake asphalt as our standard and refer others to it, by making the same determinations of their characteristics as has been done with the type bitumen, it is possible to differentiate them more or less satisfactorily.

Trinidad Land Asphalt.—Of the Trinidad land asphalt deposits the author wrote, in 1892, as follows:

" La Brea Point consists of a mass of hardened pitch deposits and reefs extending some distance into the gulf and along the shore in both directions. The deposits are found in greater or less abundance at all points between the shore and the lake, and directly along the line of the road, over an area estimated at a thousand acres or more. Two feet or more of soil cover the deposit at some distance from the lake, but near it the thickness diminishes and at places bare pitch is found.

"On the point the pitch of the reefs is hard and resonant and has no cementitious value. The nearer the deposits are to the lake, however, the softer they become.

"The incline from the lake to the gulf, a distance of three-quarters of a mile, is at first about one in twenty-five, gradually diminishing to the shore. Near the edge of the lake there is now a rank growth of grass, followed by shrubs and trees after passing the forks of the road. In the village, cultivated land is found, and large pits filled with stagnant water, from which pitch has been excavated. Except very near the lake, the pitch excavated from the land deposits is of a very different appearance from that taken from the lake, and it is also of several kinds.

"The conchoidal masses removed from the lake, as I have said, contain large gas cavities, and in appearance and somewhat in consistency resemble a black Swiss cheese. On this account the land pitch most nearly resembling this is known as 'cheese pitch.' It occurs in different degrees of porosity and life. In addition, land pitch is found in solid masses scarcely to be distinguished from refined asphalt, and this is known as 'iron pitch.' Pitch, known as 'cokey pitch,' from having been coked by the burning of the brush over its surface, and the chocolate and friable alteration products which have originated from atmospheric action and disintegration, are also recognized."

Again in another place in the same report:

"In past times the pitch very probably continued to collect (in the lake) until it overflowed the rim of the crater, in many directions, and thus perhaps became the source of many of the land pitch deposits now found from the end of the lake to the sea."

It has also been claimed that the land pitch has reached its present position by being forced up through the soil from the same source from which the lake derives its material.

For the purpose of looking into the nature of the material from the point of view of its suitability for the asphalt paving industry this is immaterial. It is the nature and characteristics of the land asphalt deposits as they are available commercially which are of interest at this point.

Trinidad land asphalt differs from that found in the lake deposit as the result of such changes as have been brought about by its having been buried under soil and exposed to the action of groundwater and aging for many centuries, that is to say, it is a very much weathered material. The two materials are undoubtedly derived from the same original subterranean source. The land asphalt may, as has been said, have reached its present position either by overflow from the lake or by intrusion into its present position in the soil directly from the point of origin. In either case no land asphalt has been found which has not been altered in its nature owing to its present or past environment, so that it differs essentially from the lake material.

Land asphalt is very variable in character, depending upon the length of time during which it has been subjected to weathering. It is much less cheesy than lake asphalt, that is to say, it contains a smaller number of gas cavities, and is harder. Some of it has been converted by brush fires into a hard compact pitch without gas cavities, resembling refined asphalt which, from its hardness, is known as iron pitch. Some portion of the land asphalt has been converted even to coke. These two latter forms are of no interest to the paving industry and are carefully removed from the material which is collected for this purpose. Further weathering of the material from the action of soil-water converts it into a substance of a chocolate color, which is very friable. Where the weathering is carried to its ultimate conclusion only the ferruginous mineral matter is left, of a bright-red color, as is evident on the beach; where the asphalt is subjected to the continuous action of sea water it becomes very hard but is not weathered to any further degree. That is to say, water containing the salts found in sea water does not act upon it. This is important in connection with the claims that soluble salts cause disintegration of Trinidad asphalt.

Much of the asphalt found in the land deposits plainly originated in the so-called lake and is now found mingled with the soil after it has run over the rim of the lake. In consequence, the land asphalt nearest the lake is much less weathered than that at a distance. The difference can be seen from the following analyses of specimens collected near the lake and at intervals between it and the shore. For comparison an analysis of lake asphalt is given:

AVERAGE COMPOSITION OF LAKE PITCH, DRIED IN VACUO, KEARNEY COLLECTION.

	Bitumen Soluble CS_2.	Mineral Matter.	Difference Undetermined.	Bitumen Soluble Petroleum Naphtha.	Total Bitumen Soluble in Naphtha.
Average........	54.25%	36.51%	9.24%	35.41%	65.27%

AVERAGE COMPOSITION OF LAND PITCH, DRIED IN VACUO, KEARNEY COLLECTION.

Eight specimens from Lot C., near the lake.					
Average........	54.03%	36.49%	9.48%	33.02%	61.11%
Four specimens from Crown Land Lots adjoining C.					
Average........	53.81%	36.62%	9.57%	32.29%	60.01%
Five specimens from east of road, middle ground.					
Average........	52.31%	37.80%	9.89%	31.25%	59.74%
Seven specimens from Village Lots, near the Gulf.					
Average........	52.27%	37.73%	10.01%	31.42%	60.12%
General average.	53.10	37.16	9.74	31.99	60.14

It is apparent that the effect of weathering has been comparatively small in the deposits closely adjoining the lake, but that, as we proceed further on toward the shore, the change is more marked and is particularly evidenced by the decrease in bitumen present, and decrease in the percentage of malthenes. The lake pitch, so-called, has, with the naphtha used as a solvent, 65.3 per cent of its bitumen soluble in naphtha, while just outside the lake the land pitch has only 61.1 per cent, and further on only 59.7 per cent soluble. This may seem a small difference, but it is evidence of a large change. In glance pitch, examined in the same way, 24 per cent only of the entire bitumen was found to be soluble in naphtha, in lake pitch 65.3 per cent. Land pitch may, therefore, be inferred to be partly converted from lake to glance pitch.

The composition of an average commercial refined land asphalt as compared with the average lake material is well shown in the table on page 176.

Land asphalt being so dependent upon its environment for its character, it is hardly possible to determine its average composition. The extremes which are met with in recent commercial supplies are of interest (see table, page 177).

From these figures it appears that refined Trinidad land asphalt of good quality is differentiated from the lake supply by its higher specific gravity, owing to the rather larger amount of mineral matter which it contains, by a higher softening or melting-point, and somewhat lower percentage of bitumen and, in consequence of these facts, a much greater hardness at all temperatures.

Naturally the percentage of malthenes is smaller in the land than in the lake asphalt and that of fixed carbon slightly higher.

The ultimate composition of the pure bitumen of land asphalt as compared with that of lake is given in the second table on page 177.

The weathering of the bitumen has, therefore, produced essential changes in the composition of the material, there having been a loss of sulphur, probably due to its elimination as hydrogen sulphide, and an increase in carbon, due to the same cause and to the elimination of hydrogen as water during the process of condensation.

These differences, though small in themselves, are indicative of the fact that the weathered land asphalt is not the same in its character as the fresh lake material. In themselves they would not amount to a great deal unless confirmed by actual results obtained in the use of the material industrially. As a matter of fact, such confirmation is not lacking if land is used in the same way as lake asphalt, that is to say, if fluxed to an asphalt cement with ordinary paraffine petroleum residuum. In the preparation of such an asphalt cement the striking differences

REFINED TRINIDAD LAND ASPHALT.

Test number	63260	36721
Bitumen	Lake R. A.	Land R. A.
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.40	1.4196
Color of powder or streak	Blue-black	Brown-black
Lustre	Dull	Dull
Structure	Homogeneous	Homogeneous
Fracture	Semi-conchoidal	Semi-conchoidal
Odor	Asphaltic	Asphaltic
Softens	180° F.	188° F.
Flows	190° F.	198° F.
Penetration at 78° F.	7°	0°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	1.1%	1.0%
Character of residue	Smooth	Blistered
Loss, 400° F., 7 hours (fresh sample)	4.0%	3.0%
Character of residue	Blistered	Blistered
Bitumen soluble in CS_2, air temperature	56.53%	54.1%
Difference	6.97	7.9
Inorganic or mineral matter	36.50	38.0
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	35.6%	33.5%
This is per cent of total bitumen	63.1	61.9
Per cent of soluble bitumen removed by H_2SO_4	61.3	64.8
Per cent of total bitumen as saturated hydrocarbons	24.4	21.8
Bitumen soluble in 62° naphtha	41.7%	38.2%
This is per cent of total bitumen	73.9	70.6
Carbenes:		
Bitumen more soluble in carbon tetrachloride, air temperature	1.3%	0.0%
Bitumen yields on ignition:		
Fixed carbon	10.8%	12.9%
Sulphur	6.2%	5.0%

REFINED TRINIDAD LAND ASPHALT. (EXTREMES IN COMPOSITION.)

PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.400	1.450
Softens	188° F.	220° F.
Flows	198° F.	230° F.
Flow in per cent of Trinidad lake = 100%	83%	15%
CHEMICAL CHARACTERISTICS.		
Bitumen soluble in CS_2, air temperature	55.0%	52.0%
Difference	7.5	9.5
Inorganic or mineral matter	37.5	38.5
	100.0	100.0
Per cent of total bitumen soluble in 88° naphtha, air temperature	63.0	52.0
Per cent of soluble bitumen removed by H_2SO_4	62.0	64.8
Per cent of total bitumen soluble in 62° naphtha	71.0	60.0
Bitumen yields on ignition:		
Fixed carbon	12.9	14.0

COMPARISON OF ULTIMATE COMPOSITION OF PURE BITUMEN, TRINIDAD LAND AND LAKE ASPHALT.

	Land.	Lake.
Carbon	83.7	82.33
Hydrogen	10.8	10.69
Sulphur	5.1	6.16
Nitrogen	0.5	0.81
	100.1	99.99

between lake and land asphalt are brought out by the fact that where 20 pounds of a good paraffine residuum is sufficient to make a suitable asphalt cement when added to each 100 pounds of lake asphalt, as much as 30 or more pounds of the same residuum are required to make a cement of the same consistency with land asphalt. Extended experience with surfaces laid with these two asphalt cements has shown that after 3 or 4 years service the surface laid with the land asphalt begins to show signs of deterioration and often at even shorter periods. Our practical results, therefore, confirm those obtained in the laboratory even more strikingly than might be expected.

Land asphalt, as has been seen, contains a very much weathered and hardened bitumen, much more hardened than one would be led to believe from mere analytical results and only shown by the necessity for the use of half as much again of flux in making a cement, and by the fact that when cylinders of the two asphalts of the same size are placed upon a corrugated brass plate and exposed to a high temperature, at an angle of 45°, the land asphalt flows from but 20 to 50 per cent as far in a given time as is the case with the lake asphalt. This is, of course, due to the absence of the softer hydrocarbons of the malthene series which, in the lake asphalt, are very susceptible to increase of temperature and consequently occasion the more rapid flow of the latter. The absence of these malthenes in a paving cement is a serious deficiency.

The recent advent of the heavy asphaltic oils as fluxes makes it possible, however, to supply to a certain extent the deficiencies in the bitumen of land asphalt by the addition of a suitable amount of such flux, instead of producing the required softness with a great excess of paraffine residuum, thus forming an unbalanced cement. Pavements made with such an asphalt cement have been fairly satisfactory, but are, unfortunately, uneven in character owing to the lack of uniformity of the original land asphalt, and to the large amount of skill which must be used in combining the different ingredients and to the care which the production of a uniform asphalt cement from such materials presents.

Bermudez Asphalt.—The occurrence of a deposit of asphalt in what has been called the Bermudez "Pitch Lake," in the State of Sucre, formerly Bermudez, in Venezuela, Fig. 4, has been described by the author in another place as follows:[1]

"From the mouth of the Orinoco, the northeastern coast of Venezuela, which faces Trinidad, is low and consists of vast mangrove swamps, through which run deep tidal estuaries. That portion forming part of the State of Bermudez extends inland for many miles. It lies on the opposite side of the Gulf of Paria from Trinidad. About 30 miles in an air-line from the coast the asphalt deposit, known as the Bermudez Pitch Lake, is found at the point where a northern range of foot hills comes down to the swamp.

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[1] On the Nature and Origin of Asphalt, Long Island City, N. Y., 1898

The Guanaco River, a branch of the San Juan, one of the large caños or estuaries of this region, at about 65 miles in its winding course, from its mouth, runs within 3 miles of the deposit, but it is 5 or 6 miles to a suitable wharfage site. On the other hand, towards the north a road runs to the hills and to the village of Guaryquen. These are the means of communication with the deposit. The so-called lake is situated between the edge of the swamp and the foot hills in what might be termed a savanna. It is an irregular-shaped surface with a width of about a mile and a half from north to south and about a mile east and west. Its area is a little more than 900 acres, and it is covered with vegetation, high rank grass, and shrubs, 1 to 8 feet high, with groves of large moriche palms, called morichales. One sees no dark expanse of pitch on approaching it as at the Trinidad pitch lake, and except at certain points where soft pitch is welling up, nothing of the kind can be found. The level of the surface of the deposit does not vary more than 2 feet and is largely the same as that of the surrounding swamps. In the rainy season it is mostly flooded and at all times very wet, so that any excavation will fill up with water. These conditions make it difficult to get about upon it or to excavate pitch easily.

" It is readily seen that this deposit is a very different one from that in the pitch lake of Trinidad. It seems to be in fact merely an overflow of soft pitch from several springs over this large expanse of savanna and one which has not the depth or uniformity of that at Trinidad.

" Being on a level with the mangrove swamps and with foot hills on its other side, any large amount of asphalt could hardly be held in position here, as in the old crater in Trinidad, but would burst out into the swamp and be lost, and, as far as borings have been made, they seem to indicate but a small depth anywhere as compared with that of the Trinidad lake.

" At different points there is at most a depth of 7 feet of material, while the deepest part of the soft maltha is only 9 feet and the average of pitch below the soil and coke only 4 feet. At points there is not more than 2 feet of pitch, and in the morichales or palm groves it is often 5 feet below the surface. At several points, scattered over the surface, are areas of soft pitch, or pitch that is just exuding from springs. The largest area is about 7 acres in extent and of irregular shape. This has little or no vegetation upon it, and from the constant evolution of fresh pitch is raised several feet above the level of the rest of the deposit. This soft asphalt has become hardened at the edges, but when exposed to the sun is too soft to walk upon. The material is of the nature of a maltha and it is evidently the source of all the asphalt in the lake, from these exudations the pitch having spread in every direction, so that no great depth of pitch is found even at this point.

"A careful examination of the surroundings shows that in one respect there is a resemblance between the point of evolution of the soft pitch at the Bermudez and at the Trinidad lakes. Gas is given off in considerable quantities at both places, and in both cases consists partly, at least, of hydrogen sulphide. At the Bermudez lake I was unable to determine whether it was accompanied by carbonic dioxide, but the odor of hydrogen sulphide was strong.

"The consistency of the soft pitch at the centre of the Bermudez lake is much thinner than that of the Trinidad lake. It will run like a heavy tar and does not evolve gas in the same rapid way or harden as quickly after collection. It therefore does not retain the gas which is generated in it, nor does the deposit as a whole do so to the same extent as the Trinidad pitch. Where, however, the surface of the soft pitch has toughened by exposure to the sun and air and where gas is given off beneath it, it is often raised in dome-like protuberances, the beehives which were spoken of by early visitors to the Trinidad lake. These have a thin wall of pitch and are filled with gas which readily burns, and have been seen two feet or more in height and 18 inches in diameter. They are, of course, found only near the soft spots.

"Although the pitch at the Bermudez lake is too soft to entangle and hold permanently the gas which is given off, where the pitch of medium consistency is covered with water it does not escape so readily, and thus often raises in the pools of water a mushroom-like growth of pitch by the reduction of the gravity of the mass from the included gases. These mushrooms correspond completely, except in size, with those described by Manross as existing at the Trinidad lake when he visited it. It seems, therefore, that we have to-day several of the phenomena represented at the Venezuelan lake which the hand of man has destroyed at Trinidad.

"There is, however, no evidence of the same simultaneous boiling up of water with the fresh soft pitch that has been determined at the Trinidad lake, but that there is none at all is not certain, as at the time I visited the locality heavy rains were falling which prevented the detection of a small amount. It seems, however, improbable, as the soft pitch contains little or no water and the traces found in the samples collected are probably derived from rain.

"**Hardening of the Main Mass of Pitch.**—The soft pitch, after it exudes at the centre of the Bermudez lake, undoubtedly hardens slowly on exposure, but the condition of the surface of the main mass, which is very hard and rough, and of the harder borders of the soft spots is due to other causes also.

"The edges of the areas of soft asphalt are covered here and there with masses of glance pitch and with black and brittle cinders or coke, and which seem to have been produced from the maltha by fire. This is evidently the case, since the rank growth of grass which is very dry in the dry season is particularly adapted for a rapid and intense combustion. Such fires have been even recently started intentionally and accidentally and to them are due the condition of the present surface of the deposit and the character of much of the pitch.

"The general surface of the lake is very irregular and hard. There are many very narrow and irregular channels or depressions from a few inches to 4 feet deep, filled with water, and not being easily distinguished, one often falls into them. At the foot of the growth of grass and shrubs are ridges of pitch mingled with soil and decayed vegetation, which have been plainly coked and hardened by fires of the nature which have been mentioned. When this hardened material which forms only a crust is removed, asphalt of a kind suitable for paving is found. The crust is from 1½ to 2 feet in depth and very firm, while the asphalt underneath would not begin to sustain the weight which that of the Trinidad pitch lake does easily. There are breaks in the crust here and there through which soft pitch exudes as has been described.

"It appears, therefore, that the Bermudez deposit owes its existence to the exudation of a large quantity of soft maltha, which is still going on and which has spread over a great extent; that this has hardened spontaneously in the sun, and has also, by the action of fire, been converted over almost the entire surface into a cokey crust of some depth, beneath which the best material lies and that here and there are scattered masses of glance pitch produced in a similar way from less violent action of heat. There is no evidence of a general movement and mingling of the mass of this deposit in any way that would produce a uniformity of composition as seen in the Trinidad pitch lake, although there is a certain amount of gas evolved at the soft spots where maltha exudes and some gas cavities are found in the general mass of the pitch beneath the crust."

The original Bermudez pitch, as it exudes at the soft spots, contains no mineral matter or water and is consequently an extremely pure bitumen. It has the following ultimate composition:

Carbon	82.88%
Hydrogen	10.79
Sulphur	5.87
Nitrogen	.75
	100.29

As in the case of the bitumen of Trinidad asphalt, sulphur plays an important rôle in its composition, but in the asphalt as it is used commercially much of this sulphur has disappeared, having been evolved as hydrogen sulphide, the industrial material containing less than 4 per cent.

Exposure of the soft maltha to the sun, after its evolution and chemical changes, hardens the material somewhat. The commercial supply has, however, been largely altered, owing to the fact that the rank vegetable growth which extends over the 900 or 1000 acres of the deposit has frequently been set on fire, either accidentally or intentionally, with the production of such a degree of heat as to convert much of the material on the surface to coke and that below to a harder form of bitumen than that of the original maltha. It is. of course, very evident that this conversion has not been uniform and that the product taken from the lake cannot, on this account, be in itself uniform. In a collection of some forty samples taken in 1896, the following extremes of composition were found:

EXTREMES IN THE COMPOSITION OF CRUDE BERMUDEZ ASPHALT.

	Highest.	Lowest.
CRUDE SUBSTANCE.		
Loss, 212° F., 4 days	46.20%	10.72%
" 400° F., 7 hours	13.60	4.72
DRIED SUBSTANCE.		
Specific gravity, 78° F./78° F.	1.075	1.005
Loss, 400° F., 7 hours	16.05	5.81
Softens	170° F.	140° F.
Flows	188° F.	135° F.
Bitumen soluble in CS_2, air temperature	98.52%	90.65%
Difference	6.45	0.62
Inorganic or mineral matter	3.65	0.50
Bitumen soluble, 88° naphtha, air temperature	73.05	63.40
This is per cent of total bitumen	76.55	67.78

The asphalt as it occurs in the deposit holds from 46 to 10 per cent of water and 3.6 to .5 per cent of mineral matter. These substances as well as the undetermined material, amounting to from 6 to .6 per cent, must be adventitious, and are in part, at least, derived from the vegetation with which it comes in contact and, although some of the organic matter is due to the conversion of part of the bitumen to coke by fires, the greater portion consists of roots of grasses and shrubs which penetrate the asphalt with ease.

The wide variation in the character of the material in different parts of the deposit is therefore made evident by the above figures. The high percentage of undetermined matter is not, as in Trinidad asphalt, due to the presence of clay or volatile inorganic salts.

There are other evidences of this variation derived from the examination of various cargoes of Bermudez asphalt which have been brought to this country for commercial use.

Year.	Crude.	After Drying.		
	Water.	Bitumen Soluble in CS_2.	Difference Undetermined.	Inorganic or Mineral Matter.
1898	15.8%	95.7%	2.3%	2.0%
1899	19.8	92.5	4.3	3.0
1901	....	95.0	2.5	2.5
1902 Good sample	23.9	95.7	2.8	1.5
Poor “	53.2	89.2	9.0	1.8
1903 Good sample	29.9	97.0	1.5	1.5
Poor “	33.3	95.5	2.9	1.6

Refined Bermudez Asphalt.—When the crude Bermudez asphalt, as it is taken from the deposit, is melted and dried it becomes the refined Bermudez asphalt of commerce and it is, of course, variable in character like the crude material it is derived from. The loss of light oils in the softer material has a tendency to bring all the refined asphalt more nearly to a uniform condition than would be expected. There are, however, decided differences not only as regards its physical characteristics but also chemically.

The variation in the consistency is well shown by the relative length to which various lots of this asphalt will flow on an inclined plane at temperatures above the softening point. For several cargoes in this way the following data were obtained:

PER CENT OF FLOW.

Original material in use in Washington, D. C., 1893	100.0%
Importation of 1895	73.5
“ “ 1898	73.0
“ “ March, 1899	50.0
“ “ May “	41.6
“ “ June “	73.3
“ “ 1903	125.0

From the preceding figures it appears that while the first material brought to this country was quite soft, the refined asphalt became harder in subsequent years and recently is again softer owing to the fact that the crude asphalt has been collected of late at points nearer the maltha springs.

In consequence of this every lot of Bermudez asphalt must be handled in its own peculiar way, and in this respect it compares unfavorably with Trinidad lake asphalt which is, as has been seen, extremely uniform.

The percentage of bitumen in the refined material varies as well as the consistency, ranging from 93 to 97 per cent, but will usually average 95 per cent.

The data given in the tables on pages 186 and 187 show the physical properties and approximate chemical composition of refined Bermudez asphalt available on the market in 1900 and 1903.

Bermudez asphalt is a comparatively pure bitumen and consequently possesses the lustre of such material instead of the dull fracture of Trinidad bitumen which is due to the presence of mineral matter. It has a uniform structure with here and there small particles of vegetable organic matter. The fracture at low temperature is somewhat conchoidal and the consistency, as shown on the Bowen penetration machine, ranges from 22 to 26°. The specific gravity of the material is 1.08, somewhat higher than that of the pure bitumen of Trinidad asphalt, on account of the presence of a certain amount of mineral matter. The hydrocarbons composing the bitumen consist to a very considerable extent of such as are volatile at 400° F., or even at 325° F. In this respect it is markedly different from Trinidad lake asphalt. Bermudez asphalt differs from Trinidad lake asphalt in containing a larger percentage of malthenes, which accounts for its greater softness. As this percentage becomes increased the softer is the consistency of the asphalt, as appears from the fact that the softer refined material of 1903 contains 71.9 per cent of malthenes, where that of 1900 contained but 65.4 per cent.

The percentage of saturated hydrocarbons unacted upon by sulphuric acid in Bermudez asphalt is about the same as that found in Trinidad lake asphalt, so that the bitumens in the two asphalts do not differ essentially in this respect.

The undetermined matter not of a bituminous nature in Bermudez is, as a rule, very much smaller than in Trinidad asphalt and

REFINED BERMUDEZ ASPHALT.

Test number	44412	67753
Year	1900	1903
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.0823	1.0575
Color of powder or streak	Black	Black
Lustre	Bright	Bright
Structure	Uniform	Uniform
Fracture	Semi-conchoidal	Semi-conchoidal
Hardness, original substance	Soft	Soft
Odor	Asphaltic	Asphaltic
Softens	170° F.	160° F.
Flows	180° F.	170° F.
Penetration at 78° F.	22°	26°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	3.0%	4.4%
Character of residue	Smooth	Smooth
Loss, 400° F., 7 hours (fresh sample)	8.2%	9.5%
Character of residue	Wrinkled	Shrunken
Bitumen soluble in CS_2, air temperature	95.0%	96.0%
Difference	2.5	2.0
Inorganic or mineral matter	2.5	2.0
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	62.2%	69.1%
This is per cent of total bitumen	65.4	71.9
Per cent of soluble bitumen removed by H_2SO_4	62.4	67.4
Per cent of total bitumen as saturated hydrocarbons	24.4	23.4
Bitumen soluble in 62° naphtha	69.2%	75.9%
This is per cent of total bitumen	72.8	79.0
Carbenes:		
Per cent bitumen insoluble in carbon tetrachloride, air temperature	0.1%	1.1%
Bitumen yields on ignition:		
Fixed carbon	13.4%	14.0%
Sulphur	4.0%	

EXTREMES IN THE COMPOSITION OF REFINED BERMUDEZ ASPHALT.

PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.085	1.057
Flow in per cent of average	41.6%	178%
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	5.5%	1.5%
Loss, 400° F., 7 hours (fresh sample)	9.5%	4.5%
Bitumen soluble in CS_2, air temperature	93.0%	96.8%
Difference	5.0	1.4
Inorganic or mineral matter	2.0	1.8
	100.0	100.0
Malthenes:		
Per cent total bitumen soluble in 88° naphtha, air temperature	65.0	73.0
Per cent total bitumen soluble in 62° naphtha	72.0	83.0
Bitumen yields on ignition:		
Fixed carbon	14.0	13.5

of an entirely different origin. In Bermudez asphalt it is derived almost entirely from vegetable organic matter in the shape of grasses and twigs with which the pitch has become contaminated. As a result of this, when the asphalt is made into a cement with a flux and maintained in a melted condition for a considerable period of time, this settles out on the bottom of the melting-tank as the gummy material which has been mentioned by the persons not further investigating its nature. If this gummy material is extracted with carbon disulphide, the vegetable nature of the material will be revealed at once.

If the ultimate composition of the bitumen of Bermudez asphalt where it exudes into the lake and that of the pure Trinidad bitumen are compared, it will be noticed that they agree very closely in their composition (see table, page 188).

The percentage of fixed carbon which Bermudez refined asphalt yields on ignition is much higher than that found in Trinidad

COMPARISON OF ULTIMATE COMPOSITION OF PURE BITUMEN, BERMUDEZ AND TRINIDAD ASPHALT.

	Bermudez, Pure Bitumen.	Trinidad, Pure Bitumen.
Carbon	82.88%	82.33%
Hydrogen	10.79	10.69
Sulphur	5.87	6.16
Nitrogen	.75	.81
	100.29	99.99

asphalt and it is an amount which is usually characteristic of all the native bitumens which are distinctly asphaltic in their nature.

The amount of sulphur is greater in the softer than in the harder varieties.

From the preceding data the two most important asphalts in use in the paving industry may be compared with the following results:

Trinidad asphalt is one which carries a very considerable amount of mineral matter which acts as a filler. Bermudez asphalt is a nearly pure bitumen. Trinidad asphalt is very stable at high temperatures and but little susceptible to change. Bermudez asphalt volatilizes an appreciable amount of light oils at high temperatures and hardens very rapidly. Bermudez asphalt contains a larger percentage of malthenes than Trinidad and on this account is more susceptible to temperature changes. Finally, Trinidad asphalt is a substance of fixed and extremely uniform composition, while Bermudez asphalt is most variable in this respect, material from different parts of the deposit showing great lack of uniformity in both its physical and chemical properties. The relative merits of the two materials from an industrial point of view will be considered later when surface mixtures are under discussion.

Maracaibo Asphalt.—The asphalt used in the paving industry, known as Maracaibo asphalt, is put upon the market by the United States and Venezuela Company. It is found in the State of Zulia, west of the Gulf of Maracaibo, on the river Limon, about 50 miles west from the City of Maracaibo, as shown on the accompanying map, Fig. 5. The principal deposit is known as that of Inciarte.

It is an exudation, from maltha springs, of bitumen which is gathered up and crudely refined, after which it is floated down the river to the village of Toas, at the opening of Maracaibo Lake into the Gulf, from which point it is shipped to the United States.

The material resembles and possesses many of the characteristics of the crude Bermudez asphalt, but it is distinguished from it by having a markedly rank odor suggestive of unsaturated hydrocarbons and of sulphur derivatives This odor may, however, be due somewhat to cracking which has taken place during refining, since in the analysis of the material numbered 66923 seventeen per cent of the bitumen is in the form of carbenes insoluble in cold carbon tetrachloride, while in the samples collected in 1904 less than two per cent is in this form.

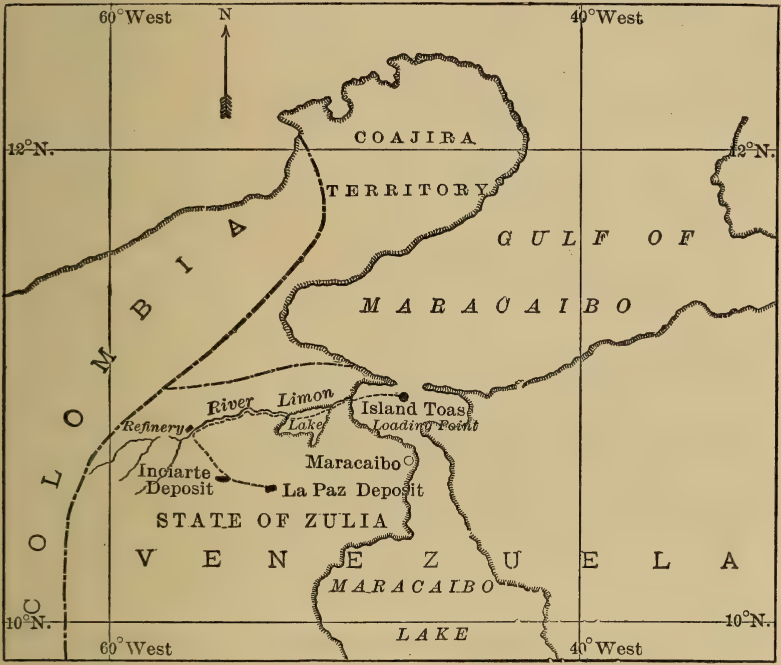

FIG. 5.

Five analyses of the crudely refined material made in the New York Testing Laboratory have resulted as follows:

	MARACAIBO
Test number	60380
Date sample received	6–19–02
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.0784
Color of powder or streak	Black
Lustre	Bright
Structure	Uniform-homogeneous
Fracture	Semi-conchoidal
Hardness, original substance	1
Odor	Strong
Softens	280° F.
Flows	300° F.
Penetration at 78° F.	8°
CHEMICAL CHARACTERISTICS.	
Original substance:	
Loss, 212° F., 1 hour	Trace
Dry substance:	
Loss, 325° F., 7 hours	5.3%[1]
Character of residue	....
Loss, 400° F., 7 hours (fresh sample)	....
Character of residue	....
Bitumen soluble in CS_2, air temperature	92.2%
Difference	6.3
Inorganic or mineral matter	1.5
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	45.8%
This is per cent of total bitumen	49.7
Per cent of soluble bitumen removed by H_2SO_4	....
Per cent of total bitumen as saturated hydrocarbons	....
Bitumen soluble in 62° naphtha	49.7%
This is per cent of total bitumen	53.5
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	....
Bitumen yields on ignition:	
Fixed carbon	19.0%
Vegetable organic matter	....

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[1] Loss determined in open dish temperature 325° to 350° F.

ASPHALT.

61047	66923	72214	72215
8–20–02	10–19–03	8–25–04	8–25–04
1.0634	1.0638	1.0660	1.0621
Black	Black	Black	Black
Bright	Bright	Bright	Bright
Uniform	Uniform	Uniform	Uniform
Semi-conchoidal	Semi-conchoidal	Semi-conchoidal	Semi-conchoidal
Soft	Soft	Soft	Soft
Strong	Strong	Strong	Strong
220° F.	200° F.	215° F.	195° F.
230° F.	210° F.	230° F.	210° F.
25°	20°	27°	26°
Trace	.3%		
4.5%[1]	2.7%	1.5%	1.5%
....	Blistered	Smooth	Smooth
....	4.7%	5.8%	6.0%
....	Much blistered	Blistered	Blistered
94.0%	96.8%	92.2%	94.3%
4.5%	1.4	2.0	2.1
1.5	1.8	5.8	3.6
100.0	100.0	100.0	100.0
54.5%	45.7%	53.4%	53.9%
57.9	47.2	57.9	57.2
....	46.4	48.5	49.2
....	25.3	25.5	29.1
59.5%	51.5%		
63.3	53.2		
....	17.5%[2]	1.5%	1.3%
15.0%	18.0%	17.0%	16.9%
....	8.0%		

---

[2] Duplicate 17.8%.

It appears from the preceding data that Maracaibo asphalt, like that from the Bermudez lake, contains considerable vegetable organic matter. On re-refining in the laboratory it has a density corresponding to the pure bitumen of Trinidad lake asphalt, that is to say, somewhat less than that of Bermudez, and a very considerable degree of purity, from 92 to 97 per cent. The refined material is soft enough to be indented with the finger-nail. Apart from the preceding characteristics it differs in other respects from Bermudez asphalt and from other asphalts with which we are acquainted. Its softening-point is not only higher than that of Bermudez asphalt but even that of Trinidad. It contains a very small percentage of malthenes, which might be expected from its high softening-point, but not from its consistency. The percentage of saturated hydrocarbons found in the malthenes is 25 to 29 per cent. The percentage of fixed carbon obtained on ignition is higher than that found in the normal asphalts, reaching 18 per cent. On heating it to a temperature not above 325° F. gas is evolved showing that the bitumen is unstable and in a state of change. What effect these peculiarities may produce in the asphalt pavements constructed with it time and experience alone can tell.

Cuban Asphalts.—Many different forms of native bitumens are found in the island of Cuba but the deposits are of such small extent in any one place that they are of no great commercial interest, except that they are imported in small amounts for the manufacture of varnishes and in one or two instances for paving purposes.

Solid bitumen, in the form of grahamite, has been mined in the Provinces of Pinar del Rio and Havana, but no attempts have been made to utilize these in the paving industry. In the neighborhood of the village of Bejucal, 18 miles south of Havana, there are several mines of bitumen of an asphaltic nature, one of which has been worked on a commercial scale and utilized in the United States in the construction of pavements in Washington, D. C. The bitumen is more or less variable. A specimen of it had the following composition:

ASPHALT FROM BEJUCAL DISTRICT, CUBA.

Test number	22220
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.305
Color of powder or streak	Red-brown
Lustre	Dull
Structure	Compact
Fracture	Semi-conchoidal
Hardness	2
Odor	Asphaltic
Softens	230° F
Flows	240° F
Penetration at 78° F	0°
CHEMICAL CHARACTERISTICS.	
Dry substance:	
Loss, 325° F., 7 hours	.88%
Character of residue	Cracked
Loss, 400° F., 7 hours (fresh sample)	1.50%
Character of residue	Wrinkled
Bitumen soluble in CS_2, air temperature	75.1%
Difference	3.5
Inorganic or mineral matter	21.4
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	32.4%
This is per cent of total bitumen	43.1
Per cent of soluble bitumen removed by H_2SO_4	60.5
Per cent of total bitumen as saturated hydrocarbons	17.0
Bitumen soluble in 62° naphtha	39.6%
This is per cent of total bitumen	52.7
Carbenes:	
Bitumen more soluble in carbon tetrachloride, air temperature	1.6%
Bitumen yields on ignition:	
Fixed carbon	25.0%
Sulphur	8.3%

In general appearance the Bejucal asphalt resembles the Trinidad refined material. It contains about 21 per cent of mineral matter in the form of silica and silicates and 75 per cent of bitumen. The specific gravity of the asphalt corresponds to a mixture of bitumen and mineral matter in these proportions. It has a very high softening point. The percentage of its total bitumen in the form of saturated hydrocarbons as revealed by the action of sulphuric acid on the malthenes soluble in 88° naphtha is smaller than that in Trinidad asphalt. It contains a large percentage of sulphur and yields a high percentage of fixed carbon, larger than that usually found in any of the asphalts. In this respect it is more closely allied to the grahamites than to the asphalts, and it may perhaps eventually be necessary to classify it with the latter form of bitumen. As might be expected from its extreme hardness, the percentage of malthenes is only about two-thirds as much as that found in Trinidad and Bermudez asphalt, and this necessitates the use of a heavy asphaltic flux in the preparation of a satisfactory asphalt cement from this material.

In the neighborhood of the Bejucal mine are several others, partial examinations of which have been made giving the results tabulated on page 195.

Mexican Asphalt.—Native bitumen in the shape of maltha and in a more or less solid form is of frequent occurrence in Mexico, especially along the coast of the Gulf of Mexico, in the States of Tamaulipas and Vera Cruz. In the neighborhood of Tampico and Tuxpan attempts have been made for many years to work the large effusions of maltha which occur there. At none of these deposits, however, is there a sufficient amount of bitumen available to make the material of commercial importance. Lots of several hundred tons have, however, been collected and shipped to the United States and used in pavements, so that it may be a matter of interest to determine what the character of the bitumen is.

Asphalt Effusions on the Tamesi River.—At about 45 miles from Tampico and 25 miles from Los Esteros, a station on the Me. & Gulf R.R., there are large tar springs. From these effusions some hundreds of tons of asphalt have been collected from time

DEPOSITS IN THE NEIGHBORHOOD OF THE BEJUCAL MINE, CUBA.

Test number	....	22221
Name of mine	"Angelo Elmira"	"Raboul"
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.348	1.306
Color of powder or streak	Dark brown	Brown
Lustre	None	None
Structure	Uniform	Brecciated
Fracture	Semi-conchoidal	Conchoidal
Hardness, original substance	3	2
Softens	245° F.	240° F.
Flows	270° F.	250° F.
Penetration at 78° F.	0°	0°
CHEMICAL CHARACTERISTICS.		
Original substance:		
Loss, 212° F., 1 hour	3.2%	.4%
Bitumen soluble in CS_2, air temperature	68.6%	73.0%
Difference	3.5	4.0
Inorganic or mineral matter	27.9	23.0
	100.0	100.0
Malthenes:		
Per cent of total bitumen soluble in 88° naphtha, air temperature	36.6%	49.3%
Per cent of total bitumen soluble in 62° naphtha	....	64.5%
Carbenes:		
Bitumen insoluble in carbon tetrachloride, air temperature	....	14.3%
Bitumen yields on ignition:		
Fixed carbon	....	17.4%

to time and shipped to the United States. The material is not of uniform composition, samples collected in 1899 and examined in the author's laboratory having the characteristics given in the first table on page 196 and in the table on page 197.

It appears that this bitumen although usually originally quite hard, as shown by the penetration at 78° F., loses a large amount of volatile matter on heating and becomes converted into a pitch

FROM TAMESI RIVER, MEXICO.

SAMPLES COLLECTED AT DEPOSIT.

Test number	28075	28076	28077	28078
Bitumen soluble in CS_2, air temp.	99.5%	68.3%	59.7%	68.1%
Difference	0.0	6.8	6.9	2.4
Inorganic or mineral matter	.5	24.9	33.4	29.5
Loss, 230° F., until dry	2.83%	13.50%	4.37%	9.66%
Loss, 325° F., 7 hours additional	17.30	7.46	6.34	13.75
Loss, 400° F., 5 hours additional	8.42	3.36	2.42	9.68
Residue after 325° and 400°	Pitch	Pitch	Pitch	Pitch
Penetration of original material at 78° F.	25°	40°	25°	57°

in all cases. The instability of the material, as revealed by this fact, would necessitate the heating of this bitumen until all the volatile portion was removed before it could be used for paving purposes satisfactorily. For this reason, as well as on account of its great lack of uniformity and the small extent of the available supply, it will not, probably, play a very important part in the asphalt paving industry.

Deposits at Chijol.—At a locality known as Chijol, 25 miles from Tampico, on the Mex. Cent. R.R., and 3 miles distant from the latter, asphalt effusions have been worked to a limited extent. A sample of this material has the following characteristics:

TEST NO. 28082.

Loss, 250° F., until dry	12.70%
Penetration at 78° F. (original substance)	66°
DRY SUBSTANCE.	
Loss, 325° F., 7 hours	13.42%
Residue after heating	Pitch
Loss, 400° F., 5 hours	7.24%
Residue after heating	Pitch
Bitumen soluble in CS_2, air temperature	91.1%
Difference	1.7
Inorganic or mineral matter	7.2
	100.0

FROM TAMESI RIVER, MEXICO.

SAMPLES SHIPPED TO NEW YORK.

Test number	44312	51471	51470
Specific gravity, 78° F./78° F. (original)	.....	1.211	1.0385
“ “ “ (dry)	1.118		
Flashes, ° F	.....	.....	308° F.
Loss, 212° F., until dry	15.0%	20.1%	10.0%
Loss on refining—water	15.0%	20.1%	
“ “ “ —impurities	8.0	22.2	
Total loss	23.0	42.3%	
Penetration of refined substance at 78° F.	16°	38°	
REFINED SUBSTANCE.			
Loss, 325° F., 7 hours	1.5%	1.8%	4.8%
Penetration of residue at 78° F.	15°	.....	70°
Loss, 400° F., 7 hours (fresh sample)	4.3%	5.5%	8.9%
Penetration of residue at 78° F.	Pitch	Pitch	50°
Loss, 325° F., 21 hours	.....	3.4%	
“ “ 28 “	.....	.....	10.4%
Loss, 400° F., 21 hours	.....	7.4%	
“ “ 28 “	.....	.....	16.9%
Bitumen soluble in CS_2, air temperature	89.1%	71.5%	99.0%
Difference	1.8	8.3	.5
Inorganic or mineral matter	9.1	20.2	.5
	100.0	100.0	100.0
Malthenes:			
Bitumen soluble in 88° naphtha, air temperature	49.5%	48.8%	73.9%
This is per cent of total bitumen soluble	55.6	68.2	74.6
Bitumen soluble in 62° naphtha	57.0%	56.2%	83.8%
This is per cent of total bitumen soluble	64.0	78.7	84.6
Bitumen yields on ignition:			
Fixed carbon	16.1%	10.4%	12.6%

It will be noted that this bitumen is very similar to the purer form of that found along the Tamesi River; that is to say, it loses large quantities of volatile matter on heating and becomes converted into a pitch. For the same reasons, as in the case of the previous bitumen, it will not prove of any importance in the paving industry, although no doubt a certain proportion of both of these materials could be incorporated with other and more satisfactory asphalts if it were a matter of economy to do so.

Deposits in the Neighborhood of Tuxpan.—54 miles from Tuxpan and 9 miles from the Tuxpan River are found large effusions of asphalt, identified under the name of the Santa Theresa deposits, attempts to develop which have been made for many years, and by many individuals, and with but little success from a commercial point of view.

A sample of the material examined in the author's laboratory had the following characteristics:

FROM DEPOSIT AT TUXPAN, MEXICO.

TEST NO. 28083.

Loss, 230° F., until dry	15.30%
Penetration at 78° F. (original substance)	76°
DRY SUBSTANCE.	
Loss, 325° F., 7 hours	12.48%
Residue after heating	Pitch
Loss, 400° F., 5 hours additional	6.84%
Residue after heating	Pitch
Bitumen soluble in CS_2, air temperature	90.3%
Difference	3.1
Inorganic or mineral matter	6.6
	100.0

This bitumen is, it will be seen, quite similar to those found near Tampico.

Deposits at Chapapote.—Effusions of asphalt which are identified under the above name occur 15 miles from Timberdar, the head of navigation of the Tuxpan River. These deposits have been worked by the Mexcian Asphalt Company, who packed the material in bags and made an effort to float it down the river. Some of the bitumen thus exported was examined by the author, giving the results tabulated on page 199.

From these data it appears that both soft and hard bitumen are found on the Chapapote Ranch, but that the former hardens very rapidly on heating, like other Mexican bitumens, FROM DEPOSIT AT CHAPAPOTE, MEXICO.

Test number	42226	28080
Specific gravity at 78° F./78° F. (original)	.....	1.0343
“ “ “ “ (dry)	1.045	
Color	.....	Black
Lustre	.....	Shining
Structure	.....	Massive
Fracture	.....	Conchoidal
Hardness	.....	2 +
Fuses	.....	Readily
Softens	.....	258° F
Flows	.....	272° F
Penetration at 78° F. (dry)	140°	
Loss, 220° F., 2 hours	11.4%	
DRY SUBSTANCE.		
Loss, 325° F., 7 hours	4.7%	
Residue after heating, penetration at 78° F.	84°	
Loss, 400° F., 7 hours (fresh sample)	13.0%	
Residue after heating, penetration at 78° F.	32°	
Bitumen soluble in CS_2, air temperature	99.0%	99.2%
Difference	.4	.1
Inorganic or mineral matter	.6	.7
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	74.1%	
This is per cent of total bitumen	74.8	
Bitumen soluble in 62° naphtha	83.5%	
This is per cent of total bitumen	84.3	
Bitumen yields on ignition:		
Fixed carbon	13.3%	21.5%

and becomes converted into a pitch. The material of this description which has been imported into the United States has been used by mixing it with other more desirable asphalts, or, where used alone, has made a more or less unsatisfactory pavement.

Malthas and solid bitumens from various other deposits in Mexico have been examined in the author's laboratory but the preceding are sufficient to illustrate the general character of the material found in that country. From information available it hardly seems possible that any of these deposits can ever furnish a reliable commercial supply. They have been mentioned in this place merely to bring out this fact and to show the character of the material that is available.

La Patera, California, Asphalt.—In Santa Barbara County, California, and about 9½ miles in an air-line west of the City of Santa Barbara, a vein or intrusion of asphalt in the shales of that neighborhood was worked for several years in the early nineties. Its geologic environment has been described by Eldridge.[1]

The material was used in the production of an asphalt cement which attracted much attention at that time, and was known as Alcatraz XX. Although the vein is now exhausted and the mine abandoned the bitumen is of some interest as being typical and illustrative of the hardest type of asphalt. In its best days it never yielded more than 70 tons in a day and generally not more than 30 or 40, the entire production in the 5 years that it was worked being less than 30,000 tons.

La Patera crude asphalt is a mixture of bitumen with the mineral matter of the adjoining shale, which is composed of sand and clay. Its fracture resembles in some respects Trinidad lake asphalt, the material being filled with small gas cavities due to the imprisonment of gas which has been evolved at an early stage in the existence of the material in the same way that takes place in Trinidad pitch. It differs from the latter in being very hard and brittle, not softening below 250° F. Material taken from the mine in 1894 contained 59 per cent of bitumen but in 1896 this fell to 55 per cent and in 1897 it had fallen to 49 per cent. The latter material had the physical properties and proximate composition given in the table on page 201.

From these figures it appears that the density corresponds to the percentage of mineral matter and bitumen which it contains. As has already been said, the softening point is very high. It of course, being so hard a material, loses but little on heating for a length of time at high temperature. The percentage of malthenes is, of course, very low and corresponds to that found in the Cuban asphalt. The percentage of hydrocarbons unacted on by sulphuric acid is low, lower even than in the Bejucal, Cuban, bitumen, and

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[1] The Asphalt and Bituminous Rock Deposits of the U. S., 1901, 442.

LA PATERA, CALIFORNIA, ASPHALT.

Test number	13541

PHYSICAL PROPERTIES.

Specific gravity, 78° F./78° F., original substance, dry	1.3808
Color of powder or streak	Black
Lustre	Dull
Structure	Uniform
Fracture	Irregular
Hardness, original substance	2
Odor	Asphaltic
Softens	260° F
Flows	300° F
Penetration at 78° F	0°

CHEMICAL CHARACTERISTICS.

Dry substance:	
Loss, 325° F., 7 hours	1.5%
Character of residue	Shrunken
Loss, 400° F., 7 hours (fresh sample)	2.5%
Character of residue	Shrunken
Bitumen soluble in CS_2, air temperature	49.3%
Difference	2.1
Inorganic or mineral matter	48.6
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	21.6%
This is per cent of total bitumen	43.8
Per cent of soluble bitumen removed by H_2SO_4	81.4
Per cent of total bitumen as saturated hydrocarbons	8.1
Bitumen soluble in 62° naphtha	26.7%
This is per cent of total bitumen	54.1
Carbenes:	
Bitumen more soluble in carbon tetrachloride, air temperature	1.7%
Bitumen yields on ignition:	
Fixed carbon	14.9%
Sulphur	6.2%

the lowest found in any asphalt. It yields about 15 per cent of fixed carbon on ignition and is, therefore, a true asphalt and in no way allied to the grahamites. The percentage of sulphur which it contains is the same as that found in Trinidad asphalt.

An asphalt of this description can only be used in combination with a dense residuum of an asphaltic petroleum. In the early days of the Alcatraz Company attempts were made to produce a paving cement by combining La Patera asphalt with the natural maltha found in the Carpinteria sands. Pavements made with this material went to pieces very rapidly, and it is not difficult, in the light of our present knowledge, to explain why this was so. The Carpinteria maltha hardens and becomes a pitch very rapidly on heating, with the result that it is impossible to guarantee that an asphalt cement made with it should have a proper consistency in an asphalt surface. Later on a heavy asphaltic petroleum residuum obtained from a petroleum produced at Summerland was used with much more satisfactory results, and some excellent pavements were laid with a cement prepared in this way, but the proportion of the La Patera asphalt to the oil, 40 to 60, was so small that it could be better regarded as an amendment to qualities lacking in the oil rather than as an asphaltic cement *per se.*

Asphalt on the More Ranch, Santa Barbara County, California.—This deposit of asphalt is of importance not on account of its size, but because the addition of perhaps a shovelful of it to each barrel of residual pitch from California petroleum has been used as a basis for the statement that the latter contains a native solid bitumen. The deposit is found on the seashore about 6 miles to the west of Santa Barbara. It has been described by Mr. J. D. Whitney in his report on the Geological Survey of California, Geology, I, 132, by Peckham in the American Jour. of Science, (2), 48, 368, and by Eldridge.

The shore here consists of an exposed cliff, 75 to 80 feet high, of sandy clay which is quite soft and easily weathered. It is much fissured and in these fissures the asphalt is found either in the shape of kidneys or veins. It can be seen at various points along the face of the cliff, where it has been exposed by the action of the waves. In places the wall rock is mixed in in fragments with the bitumen and in others it is a homogeneous material. The amount of bitumen found at any point is, therefore, very variable, as can be seen from the accompanying analyses. A few hundred tons have been taken out annually for many years and sold along the Pacific Coast. When the author examined the deposit in 1897 a kidney was being worked about 15 feet deep and about 12 feet broad, which illustrated the appearances of the material; larger masses than this are seldom found. It is evident, therefore, that the asphalt available at this point is not of commercial importance. The composition of the material is as follows:

ANALYSES OF ASPHALT FROM MORE RANCH, SANTA BARBARA COUNTY, CALIFORNIA.

Test No. 13383. From mine, collected December, 1897.
" " 13536. Supply ready for shipment on wharf.
" " 13539. Stringer in tunnel from pit.

DRY SUBSTANCE.			
Test number	13383	13536	13539
Bitumen by CS$_2$, air temperature	38.3%	40.1%	48.3%
Difference	3.4	1.4	1.2
Inorganic or mineral matter	58.3	58.5	50.5
	100.0	100.0	100.0
Malthenes: Per cent of total bitumen soluble in 88° naphtha, air temperature	63.2	63.3	59.2
Loss of crude at 212° F., 1 hour	.7%	1.4%	1.4%

It is evident that the asphalt contains too little bitumen to melt readily without the aid of a flux. The pure bitumen extracted from the asphalt is much harder than that obtained from Trinidad lake asphalt, flowing but 69 per cent as far as the latter on a corrugated plate at high temperature.

All attempts to utilize this material, except locally, have been made purely for advertising purposes in connection with the use of residual pitches, where specifications demanded the use of a native solid bitumen.

Standard Asphalt.—In the western part of Kern County, in the first tier of foot-hills on the coast range, forming the western boundary of the central valley of California, at a point called

Asphalto, at the end of a branch of the Southern Pacific Railroad from Bakersfield, an asphalt mine was in existence in the nineties which was worked by the Standard Asphalt Company of California. The company originally endeavored to work certain superficial overflows of bitumen upon the surface of the ground, but the material proving to be of no value a shaft was sunk upon a vein which penetrated the shales at this point, in the manner which has been described by Eldridge.[1] Some of the material was obtained also by running tunnels. It is of interest in this place merely to determine the character of the bitumen which was obtained.

The crude material was found in different degrees of purity and containing from 54 to 91 per cent of bitumen, as appears from the following analyses:

FROM DEPOSIT OF STANDARD ASPHALT COMPANY, CALIFORNIA.

Test number	13391	13589 No. 1	13589 No. 2	13593	13594
Bitumen by CS_2, air temperature	80.6%	90.5%	87.9%	54.3%	78.7%
Difference	7.7	0.0	3.1	6.2	4.0
Inorganic or mineral matter	11.7	9.5	9.0	39.5	17.3
	100.0	100.0	100.0	100.0	100.0
Malthenes:					
Bitumen soluble in 88° naphtha, air temperature	46.0	49.8%	43.1%	31.0%	41.0%
This is per cent of total bitumen	57.1	55.0	49.0	57.1	52.8
Loss of crude at 212° F for 1 hour	....	5.7%	14.9%	5.8%	5.9%
Bitumen yields on ignition:					
Fixed carbon	7.3				

The crude material was a compact homogeneous brownish bitumen, very much resembling gilsonite in its outward appearance, but being very much softer. Much of it, although showing no outward evidence of so doing, contained an appreciable per cent of water which, together with a certain amount of gas, is evolved on heating to 100° C. In some cases the loss reached

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[1] The Asphalt and Bituminous Rock Deposits of the United States, 1901, 449.

REFINED STANDARD ASPHALT, CALIFORNIA.

Test number	13601
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.0627
Color of powder or streak	Black
Lustre	Dull
Structure	Uniform
Fracture	Semi-conchoidal
Hardness	Soft
Odor	Asphaltic
Softens	170° F.
Flows	180° F.
Penetration at 78° F.	0 to 27°
CHEMICAL CHARACTERISTICS.	
Dry substance:	
Loss, 325° F., 7 hours	6.6%
Character of residue	Smooth
Loss, 400° F., 7 hours (fresh sample)	19.9%
Character of residue	Blistered
Bitumen soluble in CS, air temperature	89.8%
Difference	3.4
Inorganic or mineral matter	6.8
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	53.4%
This is per cent of total bitumen	59.4
Per cent of soluble bitumen removed by H_2SO_4	51.9
Per cent of total bitumen as saturated hydrocarbons	28.6
Bitumen soluble in 62° naphtha	60.0%
This is per cent of total bitumen	66.8
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	0.3%
Bitumen yields on ignition:	
Fixed carbon	8.0%

as high as 16 per cent. The run of the mine would average above 80 per cent of bitumen with 10 per cent of mineral matter and 5 per cent of moisture and gas. This bitumen is more particularly characterized and differentiated from ordinary asphalts by the fact that it yields only 7 to 8 per cent of fixed carbon, where the asphalts and gilsonite contain 14 to 15 per cent.

For the purpose of preparing the crude material for use in the paving industry it was melted with the addition of about 30 per cent of a dense asphaltic flux. The resulting product was quite hard and was further fluxed for the purpose of making an asphalt cement. This material was in use to a considerable extent in the middle West before 1900, but the mine became exhausted and it is no longer available.

The refined material had the characteristics tabulated on p. 205.

The refined Standard asphalt was a rather pure bitumen carrying but 6.8 per cent of mineral matter with 90 per cent of bitumen. The percentage of malthenes was smaller than that found in Trinidad and Bermudez asphalts, but the softening point was lower than would have been expected in such a case. As has been said the fixed carbon which this material yields is very low. Except for this its general outward resemblance to gilsonite would seem to point to the fact that the bitumen from the Standard mine must be closely allied to it. It differs from it, however, in that in gilsonite the percentage of the total bitumens present as saturated hydrocarbons is very much smaller. This may be due, however, to the fact that in gilsonite metamorphism has gone much further than in the case of the bitumen from the Standard mine. Although none of this bitumen is available for paving purposes at the present day, its character has been shown because of its uniform structure and resemblance in certain respects to gilsonite.

Good pavements were constructed with the Standard bitumen where it was properly handled, but in many cases the surface failed to give satisfaction owing to lack of skill in its use.

Other Deposits of Solid Bitumen in California.—In addition to the two abandoned deposits of asphalt which have been described, namely, those at the La Patera and Standard mines, there are numerous others scattered throughout Lower California, descriptions of which will be found in the Eldridge report on "The Asphalt and Bituminous Rock Deposits of the United States." None of them have proved, although development has been attempted in many cases, to be of the slightest commercial importance, as the material available at any one point is too small to pay for mining it, owing to the fact that the bitumen is found in fissures or veins in the shales, which always pinch out at a very moderate depth, due to the pressure exerted by the superimposed strata, and is often mixed with such a large proportion of the mineral matter from the vein walls, at times in the shape of brecciated masses scattered through the bitumen, that it is extremely difficult to handle. The only interest to the paving industry in these deposits lies in the fact that minute percentages of them have at times been added to the solid residues from asphaltic oils in order to substantiate the claim that the latter contained native solid bitumens. As a paving material none of them has ever amounted to anything nor will any of them ever do so.

SUMMARY.

In the preceding pages the characteristics of the asphalts which are or have been available to any commercial extent are given. The supply of Trinidad asphalt is extremely large in amount, uniform in character, and much more stable than any other, owing to the character of the hydrocarbons of which it is composed. Bermudez asphalt, for the same reason, is much more liable to change. Maracaibo asphalt differs essentially from all others in several respects. The data in regard to many minor deposits illustrate the very considerable variation which occurs in material included under the specific designation asphalt.

CHAPTER XI.

SOLID NATIVE BITUMENS WHICH ARE NOT ASPHALT.

It appears in our classification of native bitumens that several solid native bitumens exist which, from their peculiar characteristics, cannot be included among the asphalts. These include gilsonite, grahamite, manjak, and glance pitch. The two former are the only ones which are of any interest in the paving industry.

Gilsonite.—The occurrence of gilsonite in Utah and Colorado is thoroughly described in the report of Eldridge, which has been frequently referred to. It is only necessary in the present place to consider its physical properties and proximate chemical composition.

Gilsonite is one of, if not the purest, forms of solid bitumen found in nature. It is practically entirely soluble in carbon disulphide. It varies to a certain extent in hardness in the various deposits and veins in which it occurs. The extremes in composition in the present commercial supply appear in the following table.

GILSONITE.

PHYSICAL PROPERTIES.

Test number	92603	80343
Specific gravity, 78° F./78° F., original substance, dry	1.044	1.049
Color of powder or streak	Brown	Brown
Lustre	Lustrous	Lustrous
Structure	Homogeneous	Homogeneous
Fracture	Sub-conchoidal	Sub-conchoidal
Hardness, original substance	2	2
Softens	260° F.	300° F.
Flows	275° F.	325° F.
Penetration at 78° F.	0	0

CHEMICAL CHARACTERISTICS.

Dry substance:		
Loss, 325° F., 7 hours	.9%	2.3%
Character of residue	Smooth	Intumesces
Loss, 400° F., 7 hours	1.2	4.0
Character of residue	Smooth	Intumesces
Bitumen soluble in CS_2, air temperature	99.0%	99.9%
Inorganic or mineral matter	.0	.1
Difference	1.0	.0
Malthenes:	100.0	100.0
Bitumen soluble in 88° naphtha, air temp.	47.2	15.9%
This is per cent of total bitumen	47.7	15.9
Per cent of soluble bitumen removed by H_2SO_4	87.7	71.8
Per cent of total bitumen as saturated hydrocarbons	5.9	4.5
Bitumen soluble in 62° naphtha	67.4%	30.3%
This is per cent of total bitumen	68.1	30.4
Carbenes:		
Bitumen insoluble in carbon tetrachloride, air temperature	.0%	.4%
Bitumen yields on ignition:		
Fixed carbon	13.0%	13.4%

Gilsonite is known in the trade in two forms, firsts and seconds, the firsts being the highest-grade material in large lumps unaccompanied by powder, while the seconds are that part of the mineral which occurs nearest the vein walls, and in fragmentary particles and are made up of the less attractive product of the mine. The difference in these two grades of gilsonite is one largely of appearance rather than quality when taken from the same vein.

Gilsonite is the purest native bitumen with which we are acquainted, the best varieties containing 99.5 per cent of bitumen, and with but traces of matter not of a bituminous nature. The bitumen is equally soluble in cold carbon tetrachloride and carbon disulphide, thus differentiating it from grahamite and some of the residual pitches.

Gilsonite is more variable when taken from different deposits and at different depths.

The density of this bitumen is somewhat smaller than that of the asphalts and it has a much higher softening point, as might be expected from the fact that it is brittle and readily reduced to a reddish-brown powder, the latter characteristic alone differentiating it from the other native bitumens which give a much blacker powder. As would be expected in such a brittle material the percentage of malthenes is low, only 48 per cent of the total bitumen being soluble in 88° naphtha. The amount will vary, however, in gilsonite from different veins and from different parts of the vein, weathered material at times containing but 14 per cent, while in the best it may rise to over 70 per cent.

The hydrocarbons composing the malthenes of gilsonite are entirely different in character from those found in the asphalts. They are almost entirely composed of unsaturated hydrocarbons attacked by strong sulphuric acid, and this fact differentiates gilsonite completely from asphalt. The hydrocarbons unattacked by dilute sulphuric acid are extremely viscous, sticky, and resinous and absolutely different from those found in any other native bitumen, and there seems to be good ground for the inference that the other hydrocarbons composing gilsonite are likewise quite different from those occurring in the asphalts. A close study of these hydrocarbons will be of great interest, but our information at present available is sufficient to justify us in placing gilsonite in a class by itself among the native bitumens. Gilsonite is characterized by yielding the same percentage of fixed carbon on ignition that is found in the asphalts. This is not what would be expected from a consideration of the proximate composition of the material, which would lead us to suppose that the percentage would be higher. In material which is much weathered a higher percentage is actually found, reaching in one instance 26 per cent, and corresponding, of course, to a smaller percentage of naphtha soluble bitumen in the material, although the relation between fixed carbon and malthenes is by no means a constant one. Gilsonite is readily soluble in the heavy asphaltic residues from California and Texas petroleums and, when mixed with this in the proper proportion, makes a material which is extremely rubbery and more or less elastic and ductile.

Gilsonite in the Paving Industry.—Gilsonite has been used very successfully and to a very considerable extent in the paving industry, the peculiar rubbery nature of the cement produced from it with a heavy asphaltic flux, and the fact that this cement is less susceptible to temperature changes than those made with the ordinary asphalts, making it a very desirable material. It was not available for use, at least in the East, until the advent of the Texas asphaltic flux in 1902, as the paraffine fluxes will not cut Gilsonite satisfactorily, the result being a very short and granular substance which has no cementing power, while the California fluxes were too expensive. Gilsonite has wide applications in many industries. Successful pavements have been laid with it which have been in use for years, and it is an important constituent of varnishes, insulations, and waterproofing compounds.

Grahamite.—Grahamite is a brittle black bitumen, rarely of compact structure, which does not melt readily but merely intumesces on heating to high temperatures. It occurs in veins rather widely disseminated, but never in large amounts. Its physical properties and chemical constitution differentiate it from all other solid bitumens. Its structure is distinguished by what has been called a hackly or pencillated fracture produced apparently by the working of the brittle bitumen, induced by the movement of the vein wall. At times there is a grosser columnar structure. As types of this material, that found in Oklahoma in the Ten Mile Creek district, in the Choctaw Nation, and in Ritchie County, West Virginia, where it was originally discovered, will serve. These characteristics are shown by the analyses given on page 212.

Grahamite is an almost entirely pure bitumen soluble in carbon disulphide, naphthalene, and dead oil, but it is differentiated from the asphalts and gilsonite by the fact that it is almost entirely insoluble in naphtha, even of 62° density, and to the extent of 55.0 per

GRAHAMITE.

Test number	68940	75637
Location	Oklahoma	West Virginia
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.171	1.137
Color of powder or streak	Black	Black
Lustre	Dull	Dull
Structure	Uniform	Uniform friable
Fracture	Hackly	Irregular
Hardness, original substance	Brittle	2
Odor	None	None
Softens	Intumesces	Intumesces
Flows	“	“
Penetration at 78° F.	0°	0°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	+.1%	
Loss, 400° F., 7 hours (fresh sample)	+.5%	
Bitumen soluble in CS_2, air temperature	94.1%	97.8%
Difference	.2	.1
Inorganic or mineral matter	5.7	2.1
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temp.	.4%	3.3%
This is per cent of total bitumen	.4	3.37
Per cent of soluble bitumen removed by H_2SO_4	25.0	
Per cent of total bitumen as saturated hydrocarbons	.32	
Bitumen soluble in 62° naphtha	.7%	3.4%
This is per cent of total bitumen	.7	3.47
Carbenes:		
Bitumen insoluble in carbon tetrachloride, air temperature	68.7%	55.0%
Bitumen insoluble in hot carbon tetrachloride	48.6	1.3%
Bitumen yields on ignition:		
Fixed carbon	53.3%	41.0%
Ultimate composition:		
Carbon	.....	86.56%
Hydrogen	.....	8.68
Sulphur	.....	1.79
Difference	.....	2.97
		100.00

cent to 80.6 per cent in cold carbon tetrachloride. It is also differentiated from the asphalts and gilsonites by the fact that it yields from 30 to 50 per cent of fixed carbon on ignition. Grahamite, although not soluble in the lighter oils, is readily dissolved by the denser or semi-asphaltic fluxes, and in this condition forms a rubbery material quite similar to that produced in the same way with gilsonite. A small cylinder of it when bent upon itself will rapidly return to its original form. It lacks ductility, that is to say, it is very short when a cylinder of it is drawn out.

A similar deposit of grahamite is found in Middle Park, Colorado. This material is inaccessible and of no commercial importance. It has the composition given on page 214.

It is apparent from the results of the analyses of the 3 grahamites that the different deposits vary in the degree to which the molecule has been condensed, as shown by the percentage of bitumen insoluble in cold carbon tetrachloride.

It has also been found that grahamite can be divided into two classes, those containing sulphur and those containing oxygen.

As has been said, numerous deposits of grahamite are found in Cuba, Mexico, Trinidad, and elsewhere, but they are of no commercial importance as far as the asphalt paving industry is concerned, although of great interest from a purely scientific point of view. These will be described by the writer in another place.

Grahamite has a number of industrial uses. Successful pavements have been constructed with it in combination with gilsonite and heavy asphaltic fluxes. Mastic made with it is more resistant to grease and oil than the ordinary type, and it has been made a constituent of varnishes, of rubber substitutes, and of filler for brick and stone blocks. When cut with heavy asphaltic flux it is even more rubbery and elastic than gilsonite under the same circumstances, and less susceptible to heat.

Glance Pitch and Manjak.—These bitumens are of little or no interest in connection with the paving industry, but they must be mentioned here in order to complete our description of the solid native bitumens.

Glance pitch is a material which is quite widely distributed

GRAHAMITE FROM MIDDLE PARK, COLORADO.

Test number	19162
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.160
Color of powder or streak	Black
Lustre	Dull
Structure	Uniform-homogeneous
Fracture	Columnar, scaly
Hardness, original substance	3
Odor	None
Softens	Intumesces
Flows	"
Penetration at 78° F	0°
CHEMICAL CHARACTERISTICS.	
Bitumen soluble in CS_2, air temperature	98.2%
Difference	1.7
Inorganic or mineral matter	.1
	100.0
Malthenes:	
Per cent total bitumen soluble in 88° naphtha, air temperature	.8%
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	80.6%
Bitumen yields on ignition:	
Fixed carbon	47.4%
Ultimate composition:	
Carbon	85.97%
Hydrogen	7.65
Sulphur	.93
Difference (oxygen?)	5.45
	100.00

over the world, although the best supplies come from the East, Syria, and the Dead Sea.

Manjak is found only in the island of Barbadoes. A bitumen is shipped from Trinidad under the name of manjak, but this material is really a grahamite and not a true manjak, as it does not melt and has all the properties of the latter bitumen.

The characteristics of these materials are shown by the following analyses:

EGYPTIAN GLANCE PITCH.

Test number	14145
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.097
Color of powder or streak	Black
Lustre	Lustrous
Structure	Brittle-uniform
Fracture	Conchoidal
Hardness, original substance	2
Softens	250° F.
Flows	260° F.
Penetration at 78° F	0°
CHEMICAL CHARACTERISTICS	
Bitumen soluble in CS_2, air temperature	99.7%
Difference	.2
Inorganic or mineral matter	.1
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	23.5%
This is per cent of total bitumen	23.6
Per cent of soluble bitumen removed by H_2SO_4	72.0
Bitumen soluble in 62° naphtha	36.9%
This is per cent of total bitumen	37.0
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	0.1%
Bitumen yields on ignition:	
Fixed carbon	15.0%
Ultimate composition:	
Sulphur	8.52%
Carbon	80.87
Hydrogen	10.42
Nitrogen	.19
	100.00

BARBADOES MANJAK.

Test number	14143
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	1.0844
Color of powder or streak	Dark brown
Lustre	Lustrous
Structure	Uniform
Fracture	Conchoidal
Hardness, original substance	1
Softens	230° F.
Flows	250° F.
Penetration at 78° F	0°
CHEMICAL CHARACTERISTICS.	
Bitumen soluble in CS_2, air temperature	99.2%
Difference	.5
Inorganic or mineral matter	.3
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	26.9%
This is per cent of total bitumen	27.0
Per cent of soluble bitumen removed by H_2SO_4	75.0
Bitumen soluble in 62° naphtha	40.4%
This is per cent of total bitumen	40.7
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	1.2%
Bitumen yields on ignition:	
Fixed carbon	25.0

It will be noted that glance pitch is a very brittle material, of a higher density and much higher melting-point than asphalt, of great purity and containing but a very small percentage of malthenes. It has evidently originated in the very complete hardening of asphalt either by natural causes or, exceptionally, by its exposure to heat in one way or another.

Manjak resembles it in many respects, but is distinguished from it by being more closely related to grahamite, on account of the higher percentage of fixed carbon which it contains, that obtained from glance pitch being an amount normal to asphalt, while that from manjak approaches that obtained from grahamite. It is, however, differentiated from grahamite by the fact that it actually melts, instead of intumescing only, and dissolves completely in cold carbon tetrachloride.

In both of these solid bitumens there is a very small proportion of stable hydrocarbons unattacked by sulphuric acid.

Ozocerite.—Ozocerite is a solid bitumen the principal supply of which is found in Galicia. A small amount of it is also found in Utah, in Emery and Uintah Counties. The hydrocarbons of which it is composed are solids, resembling paraffine scale. When purified it is known as ceresin and is used for the adulteration of beeswax, and as a substitute for paraffine scale, which it is superior to on account of its high melting-point. As it is a paraffine compound it is of no interest in the paving industry.

PYROBITUMENS.

Albertite.—Albertite is an extremely brittle and lustrous material. It was first described by Wetherill.[1] It "occurs filling an irregular fissure in rocks of the Subcarboniferous Age in Nova Scotia." It has since been found in Cuba, Mexico, Oklahoma, and Utah. It is not a true bitumen, but a very small part of it being soluble in the usual solvents for that substance. It yields a very high percentage of fixed carbon. Analyses of albertites from various localities which have been examined in the author's laboratory are tabulated on pages 218, 219.

Its ultimate composition is, for the Nova Scotia material,

Carbon	85.53%
Hydrogen	13.20
Sulphur	1.20
Nitrogen	.42

Albertite is usually quite free from mineral matter, but in the case of that found in Mexico it contains 22.6 per cent and a rather larger portion of bitumen soluble in carbon disulphide than in that found elsewhere.

The material is of no importance in the paving industry.

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[1] Trans. Am. Phil. Soc., Phila., 1852, 353.

ANALYSES OF

Locality	Nova Scotia	
Test number	61486	7834
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	....	1.075
Color	Black	Black
Lustre	Lustrous	Lustrous
Structure	Homogeneous	Homogeneous
Fracture	Smooth	Smooth
Hardness, original substance	.....	.....
Odor	None	None
Softens	Intumesces	Intumesces
Flows	"	"
Penetration at 78° F.	0°	0°
CHEMICAL CHARACTERISTICS.		
Original substance:		
Loss, 212° F., until dry	.....	.....
Dry substance:		
Bitumen soluble in CS_2, air temperature	9.0%	5.9%
Difference	91.0	94.1
Inorganic or mineral matter	.2	.0
	100.2	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	.....	1.5%
This is per cent of total bitumen	.....	.....
Bitumen yields on ignition:		
Fixed carbon	39.0%	29.8%
Sulphur	.....	1.2%

Wurtzilite.—Wurtzilite is a hard lustrous pyrobitumen, slightly elastic in thin fragments, which is found in Uintah County, Utah. It does not fuse at high temperatures, but a process has been devised for fluxing it with heavy malthas by gradually cracking it at high temperatures. It is practically insoluble in carbon disulphide and heavy residuum.

ALBERTITE.

Utah.	Utah.	Mexico.	Cuba.	Oklahoma.	
19187	30495	36326	62989	74995 Bright sample	74995 Dull sample
1.092	1.099	.....	1.204		
Black	Brown-black	Black	Black		
Partly lustrous	Partly lustrous	Dull	Lustrous		
.....	.....	Homogeneous			
Irregular	Irregular	Irregular	Semi-conchoidal		
Brittle	2	2	2		
None	None	None	None		
Does not intumesce	Intumesces	Intumesces	Intumesces		
.....	"	"	"		
0°	0°	0°	0°		
.....	2.25%	.2%	.1%		
5.6%	3.4%	11.9%	Trace	1.6%	6.8%
94.2	96.4	61.9	98.9%	87.7	71.2
.2	.2	26.2	1.1	10.7	22.0
100.0	100.0	100.0	100.0	100.0	100.0
.....	Trace	3.2%	.....	.0%	.0%
.....	.....	23.4			
37.0%	40.4%	39.0%	53.0%	33.6%	54.2%
1.06					

The amount available is too small to make it of any importance in the paving industry, and this and the preceding pyrobitumen have been merely mentioned to complete our illustration of the various types which are found in nature. Some determinations of its characteristics resulted as follows:

WURTZILITE.

Test number	15270	31724	72684
PHYSICAL PROPERTIES.			
Specific gravity, 78° F./78° F., original substance, dry	1.0544	1.0490	1.0639
CHEMICAL CHARACTERISTICS.			
Bitumen soluble in CS_2, air temperature.	......	12.8%	6.7%
Bitumen yields on ignition:			
Fixed carbon	8.8%	5.2%	8.3%

SUMMARY.

The several solid native bitumens which are not asphalts are shown to have interesting characteristics and some valuable properties.

Grahamite, like gilsonite, can be fluxed with asphaltic oils at very high temperature and in such form makes a very rubbery material of value in the paving industry as well as for paint and varnish and for waterproofing. The use of Grahamite in the construction of pavements is limited by the fact that it may be utilized only at high temperatures with certain modifications and that the supply is extremely small.

The other solid bitumens are of interest only in connection with the manufacture of varnishes and for insulating purposes; they do not offer inducements towards introducing them into the paving industry.

CHAPTER XII.

ASPHALTIC SANDS AND LIMESTONES.

Kentucky.—Sands are found in Carter and Boyd Counties in the northeastern part of Kentucky and in the counties of Breckenridge, Grayson, Edmonson, Warren, and Logan in the western part of the State. The geological relations of these sands and the manner of their occurrence is described in great detail by Eldridge.[1]

In the present place it will only be necessary to show the nature of the sands and that of the bitumen with which they are impregnated in order to determine their availability for paving purposes.

In a general way it may be said that the sands are all composed of loose grains which fall to pieces on the extraction of the bitumen and are in no case sandstone. The bitumen impregnating the sand is not a solid one, but consists of a maltha which pulls out to a long thread at ordinary temperature or, in rare instances, after extraction has a penetration as low as 60°. The bitumen from the Green River sand which was extracted with carbon disulphide had the following characteristics:

BITUMEN EXTRACTED FROM BITUMINOUS SAND FROM THE GREEN RIVER DEPOSIT, KENTUCKY.

Penetraton at 78° F.	60°
Per cent of total bitumen soluble in 88° naphtha	65.4
Per cent of soluble bitumen acted upon by H_2SO_4	15.0
Bitumen contains soft paraffines	2.6%
Yields on ignition:	
Fixed carbon	15.0%

It appears from the preceding figures that the bitumen of the Kentucky sands is semi-asphaltic in that it yields an amount of fixed carbon corresponding to that found in the asphalts, but at the same time contains some soft paraffine scale, and is largely made up of stable hydrocarbons which are not attacked by sulphuric acid. As a rule, the bitumen is, however, too soft to be suitable for use as a paving cement until the volatile oils have been driven off by heating. When the bitumen is heated, however, it is, as in the case of the California Carpinteria sands, rapidly converted into a hard pitch. The Kentucky sands contain on the average about 6.5 per cent of bitumen of the nature which has been described. In exceptional cases it reaches 13 per cent. The characteristics of the sands in particular localities are as follows:

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[1] The Asphalt and Bituminous Rock Deposits of the United States, 1901.

Carter County.—A deposit of bituminous sand occurs on Soldier Creek in Carter County, as described by Eldridge. Samples of this sand analyzed in the author's laboratory in 1898 and 1900 had the following composition:

BITUMINOUS SAND FROM SOLDIER CREEK, CARTER COUNTY, KENTUCKY.

Test number..................	10681	33896
	1898	1900
Bitumen soluble in CS_2.......	8.2%	9.1%
Passing 200-mesh sieve......	4.5	3.9
“ 100- “ “	21.2	35.0
“ 80- “ “	31.0	36.0
“ 50- “ “	27.6	15.0
“ 40- “ “	3.5	1.0
“ 30- “ “	2.8	0.0
“ 20- “ “	1.2	0.0
	100.0	100.0

The extracted bitumen is a soft maltha flowing slowly at 78° F., and hardening rapidly on heating, with a loss of 12 per cent.

Breckenridge County.—The sandstones of Breckenridge County are worked by the Breckenridge Asphalt Company and lie, according to Eldridge, two miles south of Garfield, in a bed 14 feet thick, the lower 7 or 8 feet being much more enriched than the upper portion. Specimens examined in the author's laboratory had the following composition:

BITUMINOUS SAND FROM DEPOSIT OF BRECKENRIDGE ASPHALT COMPANY, BRECKENRIDGE COUNTY, KENTUCKY.

TEST NO. 9264.

	Richer Portion.	Poorer Portion.
Bitumen soluble in CS_2......	7.7%	4.3%
Passing 200-mesh sieve.....	7.2	10.6
" 100- " "	26.6	26.6
" 80- " "	26.0	26.0
" 50- " "	29.4	29.4
" 40- " "	2.5	2.5
" 30- " "	0.4	0.4
" 20- " "	0.2	0.2
	100.0	100.0

The extracted bitumen is a soft maltha hardening on heating, as is the case with bitumens from other Kentucky sands.

Grayson County.—Asphaltic sands are found in Grayson County in the neighborhood of Leitchfield, which Eldridge describes under the designation " Schillinger Prospects " and " Breyfogle Quarries." At the latter point sands impregnated with bitumen and seepages of a gummy consistency are found. The sands are of varying degrees of richness and the seepages of different degrees of hardness. The results of analyses of specimens of the materials which were formerly mined at this point are given in the following tables and in one on p. 225:

ASPHALTIC SANDS, GRAYSON COUNTY, KENTUCKY.

Test number..................	41187	41277	41188	49577
Bitumen soluble in CS_2..........	6%	10%	13%	13.7%
Passing 200-mesh sieve..........	4	13	5	4.3
" 100- " "	6	63	6	4.0
" 80- " "	3	11	6	6.0
" 50- " "	5	3	52	34.0
" 40- " "	7	0	18	24.0
" 30- " "	20	0	0	8.0
" 20- " "	29	0	0	3.0
" 10- " "	13	0	0	3.0
Retained on 10-mesh sieve.......	7	0	0	....
	100	100	100	100.0

BITUMEN IMPREGNATING MINERAL MATTER, GRAYSON COUNTY, KENTUCKY.

Test number	41189	41190
Specific gravity, 78° F./78° F.	1.282	1.769
Color	Black	Black
Lustre	Shining	Shining
Structure	Massive	Massive
Fracture	Irregular	Irregular
Hardness	−1	1
Odor	Asphaltic	Asphaltic
Loss, 220° F., 1 hour	7.0%	1.5%
Bitumen soluble in CS_2, air temperature	62.4%	30.0%
Difference	9.2	4.9
Inorganic or mineral matter	28.4	65.1
	100.0	100.0
Malthenes:		
Bitumen soluble 88° naphtha, air temperature	50.8%	21.9%
This is per cent of total bitumen	83.0	70.3
Bitumen soluble 62° naphtha, air temperature	54.3%	29.7%
This is per cent of total bitumen	87.0	79.0
Bitumen yields on ignition:		
Fixed carbon	12.0%	12.0%
Penetration of extracted bitumen at 78° F.	45°	35°

It will be noticed that in the case of the sand some of it is quite rich in bitumen and other parts of it quite poor. The sand grains are extremely coarse, the majority of them being of 50- and 40-mesh size in one instance, and larger than 30 in another. Such a sand grading alone would make this material unsuitable for use in an asphalt surface.

The mixture of loose mineral matter and asphalt contains a large percentage of bitumen which is very hard in consistency but is hardly asphaltic in nature, as the amount of fixed carbon which it yields is only 12 per cent.

The seepages vary in consistency from that of a mere maltha to that of a bitumen having a penetration of only 35°. In the

SEEPAGES, GRAYSON COUNTY, KENTUCKY.

Test number	41192	41277
Specific gravity 78° F./78° F.	.....	.9783
Loss, 220° F., 1 hour	26.8%	19.2%
Dry substance:		
Loss, 325° F., 7 hours	4.1%	
" , 400° F., " " (fresh sample)	12.4	
Character of residue after 325° F.	Too soft for penetration.	
" " " " 400° F.	22°	
Bitumen soluble in CS_2, air temperature	89.8%	88.6%
Difference	0.3	5.5
Inorganic or mineral matter	9.9	5.9
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	74.5%	54.0%
This is per cent of total bitumen	83.0	61.2
Bitumen soluble in 62° naphtha, air temperature	81.0%	60.8%
This is per cent of total bitumen	90.2	68.7
Bitumen yields on ignition:		
Fixed carbon	.....	15.6%
Penetration of extracted bitumen at 78° F.	.....	35°

latter case the material seems to be more asphaltic, as it yields 15.6 per cent of fixed carbon.

A deposit identified to the author as being from Ferry's quarry, in Grayson County, has the following characteristics:

BITUMINOUS SAND FROM FERRY'S QUARRY, GRAYSON COUNTY, KENTUCKY.

TEST NO. 7218.

Bitumen soluble in CS_2	7.7%
Passing 200-mesh sieve	17.7
" 100- " "	34.5
" 80- " "	36.4
" 50- " "	3.7
	100.0

EXTRACTED BITUMEN.

Bitumen soluble in 88° naphtha, air temperature	71.4%
Loss, 400° F., 7 hours	18.6
Penetration at 78° F.	81°

This material is composed of an extremely fine sand, quite different from that found at the Breyfogle quarry, and contains between 7 and 8 per cent of bitumen, which, after heating for 7 hours at 400° F., loses 18.6 per cent. This bitumen, before heating, has a penetration of 81°.

Edmonson County.—Eldridge states that in Edmonson County there are many deposits of asphaltic sandstone and small tar springs, none of which he considers to be of any value. They have not been examined in the author's laboratory.

Warren County.—Along the Green River, in Warren County, are deposits of bituminous sand which have been worked for paving purposes, the characteristics of which are that they consist of quartz sand impregnated with from 6 to 9 per cent of very soft maltha.

At Youngs Ferry the Green River Asphalt Company has opened a quarry the sand from which has the following compositions:

BITUMINOUS SAND FROM DEPOSIT OF GREEN RIVER ASPHALT COMPANY, WARREN COUNTY, KENTUCKY.

Test number	61873	27606
Bitumen soluble in CS_2	6.1%	8.8%
Passing 200-mesh sieve	14.9	11.3
" 100- " "	48.0	10.0
" 80- " "	19.0	23.0
" 50- " "	12.0	37.1
" 40- " "	0.0	8.0
" 30- " "	0.0	.9
" 20- " "	0.0	.9
" 10- " "	0.0	.0
	100.0	100.0
Loss, 212° F., 1 hour		1.5%

EXTRACTED BITUMEN.

Penetration at 78° F...... Too soft, pulls to a thread

Fixed carbon.............................. 11.8%

The first column represents the average composition of that which has been taken out for paving purposes. It is very evident that the small percentage of bitumen in this sand, aside from the fact that it is not of a strictly asphaltic nature, as it yields but 11.8 per cent of fixed carbon, would make it impossible to produce a satisfactory surface mixture with it without some amendment.

Near Brownsville the Rock Creek Natural Asphalt Company has worked another sand which is coarser than that found at Youngs Ferry, as shown by the following analysis:

BITUMINOUS SANDSTONE NEAR BROWNSVILLE, KENTUCKY.

TEST No. 61363.

Bitumen soluble in CS_2	6.6%
Passing 200-mesh sieve.	12.4
" 100- " "	7.0
" 80- " "	3.0
" 50- " "	18.0
" 40- " "	30.0
" 30- " "	13.0
" 20- " "	6.0
" 10- " "	4.0
	100.0

This material, like that from the Youngs Ferry deposit, is not sufficiently rich in bitumen to make it of any value.

Oozings of this bitumen, collected in drill-holes, had the composition given in table on page 228 under test No. 40894.

The bitumen in the sands at this point is a very soft one, having a penetration of 193°. It hardens rapidly on heating, the residue after 7 hours at 400° F. having a penetration of only 12°. Such an unstable bitumen, aside from the unsatisfactory grading of the sand, makes this sand unavailable for the production of a satisfactory pavement.

Logan County.—Eldridge states: "The deposits of bituminous sandstone in Logan County lie in its northern half. . . . A single quarry of the Standard Asphalt Company has been opened about 5 miles northeast of Russellville."

The average material from the base of the quarry has the composition given in table on page 228, test No. 19938.

The bitumen which oozes from the sand has been examined with the results given in table on page 229.

OOZINGS OF BITUMEN FROM NEAR BROWNSVILLE, KENTUCKY.

Test No. 40894.

Loss, 212° F., until dry	22.8%

DRY SUBSTANCE.

Loss, 325° F., 7 hours	11.5%
Residue after heating to 325° F	Penetration = 55°
Loss, 400° F. for 7 hours (fresh sample)	13.1%
Residue after heating to 400° F	Penetration = 12°
Bitumen soluble in CS_2, air temperature	94.4%
Difference	.5
Inorganic or mineral matter	5.1
	100.0

Malthenes:

Bitumen soluble in 88° naphtha, air temperature	75.6%
This is per cent of total bitumen	80.0
Bitumen soluble in 62° naphtha, air temperature	82.6%
This is per cent of total bitumen	88.0

EXTRACTED BITUMEN.

Penetration a 78° F =	193°

BITUMINOUS SANDSTONE, LOGAN COUNTY, KENTUCKY.

Test No. 19938.

Bitumen soluble in CS_2	7.8%
Passing 200-mesh sieve	6.2
“ 100- “ “	27.0
“ 80- “ “	31.0
“ 50- “ “	25.0
“ 40- “ “	2.0
“ 30- “ “	1.0
	100.0
Loss at 212° F.	.5%

These results show that this material, like the bitumen in the sands from other parts of Kentucky, is a maltha which hardens on heating to a very brittle substance, and on that account is not suitable for paving purposes.

BITUMEN OOZING FROM SAND, LOGAN COUNTY, KENTUCKY.

TEST NO. 21264.

Loss, 212° F., until dry	16.3%
Dry substance:	
Loss, 325° F., 7 hours	5.5%
Residue after heating to 325° F.	Too soft for penetration
Loss, 400° F., 7 hours	3.8%
Residue after heating to 400° F	Penetration = 20°
Bitumen soluble in CS_2, air temperature	62.8%
Difference	7.7
Inorganic or mineral matter	29.5
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	35.4%
This is per cent of total bitumen	56.4
Bitumen soluble in 62° naphtha, air temperature	50.6%
This is per cent of total bitumen	80.6

Importance of the Kentucky Bituminous Sands for the Paving Industry.—From the preceding data it is very evident that no satisfactory asphalt pavements can be constructed from any of the bituminous sands available in Kentucky for two reasons. In the first place the bitumen is a maltha which has no stability and hardens very much on exposure to high temperatures. In the second place it is not present in sufficient amount to cement the sand grains together satisfactorily, and finally, the sand itself is seldom graded in a way to form a satisfactory mineral aggregate. It is always deficient in filler. It may be possible, for light traffic streets, to make an asphalt surface mixture from a Kentucky sand by the addition of some hard bitumen and a satisfactory amount of filler, but when this is done it would generally be found to have been a matter of economy not to have used the bituminous sand at all, but to have started with a suitable local sand and have combined this with a proper asphalt cement and a good filler.

Actual experience with asphalt pavements constructed with

Kentucky material has confirmed all these conclusions, and it is safe to say that the sooner the attempt to work these deposits is abandoned the less money will be sunk.

Oklahoma.—Deposits of bitumen in various forms are found widely scattered over this State. Among them are several which consist of bituminous sands. Although none of them is of any great value in the paving industry, it will be of interest here to show what their composition is in order that vain attempts may not be made to utilize them at great financial loss.

Limestones saturated with bitumen are also found in the immediate neighborhood of the bituminous sands, and as attempts have been made to utilize these in conjunction with the sands they will be described at the same time.

In what Eldridge denominates the Buckhorn District, in the region east of the Washita River and in the neighborhood of Rock Creek, numerous quarries of bituminous sands and limestones have been opened by different individuals and companies and some of the material has been utilized in the construction of street pavements.

The material from the Ralston quarry, about 2 miles west-northwest of Schley and 8 miles northeast of Dougherty, has the following composition. This material is still further described by Eldridge.[1]

FROM RALSTON QUARRY, NEAR SCHLEY AND DOUGHERTY, OKLAHOMA.

TEST No. 11602.

Bitumen soluble in CS_2	5.0%
Passing 200-mesh sieve	9.7
" 100- " "	41.0
" 80- " "	29.0
" 50- " "	11.0
" 40- " "	2.0
" 30- " "	1.0
" 20- " "	1.0
" 10- " "	.3
	100.0

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[1] The Asphalt and Bitumimous Deposits of the U. S., 1901, 294.

EXTRACTED BITUMEN.

Extracted bitumen: a soft maltha, consistency of residuum.

Loss, 325° F., 7 hours	5.96%
" 400° F., 5 " (fresh sample)	9.98%
Residue after heating to 400° F.	Pulls to a long thin thread and penetrates 76°.

The Gilsonite Roofing and Paving Company's mines of bituminous limestone and asphaltic sands are found in Sections 21, 22, and 23, Range R.3.E. The Rock Creek Natural Asphalt Company own and have somewhat developed several deposits of bituminous sands and limestone rocks north of the preceding deposits, in the Buckhorn District.

The sands which have been developed to the greatest extent and used by the Rock Creek Natural Asphalt Company have the following composition:

BITUMINOUS SAND FROM BUCKHORN DISTRICT, OKLAHOMA.

Test number	30481	69086
Bitumen soluble in CS_2	12.2%	11.1%
Passing 200-mesh sieve	1.8	12.9
" 100- " "	29.0	48.0
" 80- " "	26.0	23.0
" 50- " "	30.0	5.0
" 40- " "	1.0	0.0
	100.0	100.0
Extracted bitumen at 78° F.	......	Soft

This sand is fine and somewhat variable in grading, the bitumen which it contains is a soft maltha, although it varies somewhat in accordance with the extent to which it has been weathered. The material has been combined with the limestones, a description of which follows, and fairly successful pavements have resulted from the combination in Kansas City, Mo.

The principal bituminous limestone quarries of the Gilsonite Roofing and Paving Company are known as No. 2 and No. 4, the former being found at the southeast end of the so-called Buckhorn District, while the No. 4 quarry or mine is at the western end of the District about 1 mile west of Schley and 7 miles northeast of Dougherty. The composition of these limestones is as follows:

BITUMINOUS LIMESTONE FROM BUCKHORN DISTRICT, OKLAHOMA.

TEST No. 69084.

LIME ROCK NO. 4.

Bitumen soluble in CS_2	4.3%
Carbonates and organic matter	86.8
Mineral matter insoluble in HCl	8.9
	100.0
Extracted bitumen penetrates at 78° F.	60°

LIME ROCK NO. 2.

Test number	69085	57870
Bitumen soluble in CS_2	12.1%	13.1%
Carbonates and organic matter	76.5	81.6
Mineral matter insoluble in HCl	11.4	5.3
	100.0	100.0
Extracted bitumen penetrates at 78° F.	65°	21°

In thin section under the microscope it is seen that these limestones differ entirely in their structure from those found on the Continent of Europe and which have been utilized so largely for the construction of pavements. The mineral matter in the latter consists entirely of the remains of marine animal life that are very uniformly impregnated with bitumen. The limestones from Oklahoma on the other hand, contain a very considerable proportion of hard crystalline calcite which is not impregnated at all with bitumen. On this account the latter do not compare favorably with the rock asphalts of Europe.[1]

These limestones, as has been said previously, have been combined with the sand rock to make a very satisfactory paving surface, the proportions in use being $\frac{1}{3}$ No. 2 lime rock, $\frac{1}{3}$ No. 4 lime rock, and $\frac{1}{3}$ sand rock. The sand rock supplies the flux necessary for the hard bitumen in the limestone, the latter having a penetration of only 60 to 65°, before heating, as it occurs in nature and only 20° after that operation. Such a mixture has the following composition:

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[1] See page 252.

SURFACE MIXTURE MADE FROM BITUMINOUS SAND AND LIME ROCKS FROM OKLAHOMA.

TEST NO. 48231.

Bitumen soluble in CS_2	8.2%
Passing 200-mesh sieve	18.8
" 100- " "	9.0
" 80- " "	18.0
" 50- " "	16.0
" 40- " "	4.0
" 30- " "	3.0
" 20- " "	8.0
" 10- " "	6.0
Retained on 10-mesh sieve	9.0
	100.0

It will be noticed that the bitumen in this mixture is lower than in a sand mixture of the same grading and yet it has been shown by experience that it is a satisfactory one. This is probably due to the fact that the film of asphalt on the lime rock is not necessarily as thick as that upon the sand grains and for this reason the percentage of bitumen which this mineral aggregate will carry is smaller than when the latter is of a silicious nature.

Although fairly satisfactory pavements have been made with these materials it is not probable that they will prove of any importance in the paving industry as the supply as turned out is too small to permit of obtaining a requisite quantity of uniform quality and because the greatest skill is necessary in so handling the material as to make it possible to put it down with the bitumen of a proper state of consistency, as this changes very readily on being heated in the slightest degree to too high temperature.

Brunswick District.—The District which has been named by Eldridge the "Brunswick District" lies on the Brunswick Creek immediately north of Rock Creek, to which it is a tributary, 4 miles northeast of Dougherty. The deposits here resemble those found in the Buckhorn District. They have been worked to a certain extent industrially but are probably of no great commercial interest.

Analyses of the bituminous products obtained there, made in 1898, resulted as follows:

FROM BRUNSWICK DISTRICT, OKLAHOMA.

Test No. 18656 and 18657. Fossiliferous limestone, impregnated with bitumen.
" " 18662. Bituminous sand, Kirby mine.
" " 18667. " " as shipped.
" " 18668. " " " "

Test number	18656	18657	18662	18667	18668
Bitumen soluble in CS_2	1.6%	3.1%	11.3%	9.3%	8.6%
Passing 200-mesh sieve	....	3.9	1.7	1.7	1.4
" 100- " "	....	1.0	29.0	36.0	20.0
" 80- " "	....	1.0	45.0	40.0	42.0
" 50- " "	....	11.0	13.0	13.0	28.0
" 40- " "	....	12.0	0.0	0.0	0.0
" 30- " "	....	30.0	0.0	0.0	0.0
" 20- " "	....	31.0	0.0	0.0	0.0
" 10- " "	....	7.0	0.0	0.0	0.0
		100.0	100.0	100.0	100.0

Materials received from the same locality in 1903 had the following composition:

Test number	63279	63280	63283
Bitumen soluble in CS_2	4.9%	6.8%	2.3%
Carbonates	89.1	86.4	94.1
Mineral matter insoluble in HCl	6.0	6.8	3.6
	100.0	100.0	100.0

Remarks: No. 63279. Hard compact limestone with free bitumen in small seams, somewhat crystalline.
" 63280. Same as No. 63279, containing more seams and larger ones and the latter being filled with a considerable seepage of free bitumen, aside from that impregnat- the rock.
" 63283. Same as No. 63279, unevenly impregnated with bitumen, the seams carrying free material, although to no such extent as No. 63280.

It would seem from the above data that there can be no question that the lime rock will not bear the cost of transportation.

Arbuckle Mountains.—Many deposits of bituminous sands are found in the neighborhood of the Arbuckle Mountains, some of which have been examined by the author. That occurring southeast of Woodford, close to the Henryhouse Creek, and known as the Sneider Deposit, has the following composition:

BITUMINOUS SAND FROM SNEIDER DEPOSIT, ARBUCKLE MOUNTAINS DISTRICT, OKLAHOMA.

TEST No. 30478.

Bitumen soluble in CS_2	11.1%
Passing 200-mesh sieve	8.9
“ 100- “ “	75.0
“ 80- “ “	2.0
“ 50- “ “	2.0
“ 40- “ “	1.0
“ 30- “ “	0.0
“ 20- “ “	0.0
“ 10- “ “	0.0
	100.0

The quarry is described in detail by Eldridge.[1]

Attempts have been made to extract the bitumen from this sand, industrially and the material obtained has the following properties:

EXTRACTED BITUMEN FROM BITUMINOUS SANDS FROM ARBUCKLE MOUNTAINS DISTRICT, OKLAHOMA.

TEST No. 30474.

Loss, 212° F., 1 hour	0.1%
Residue after heating to 212° F.	Too soft for penetration
DRY SUBSTANCE.	
Loss, 325° F., 7 hours	3.5%
Residue after heating to 325° F.	Penetration = 110°
Bitumen soluble in CS_2, air temperature	68.7%
Difference	1.5
Inorganic or mineral matter	29.8
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temp.	57.3%
This is per cent of total bitumen	83.4
Bitumen soluble in 62° naphtha, air temp.	62.6%
This is per cent of total bitumen	91.1
Character of extracted bitumen	Soft at 78° F.

The character of this material and the cost of obtaining it will probably exclude it from any commercial application.

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[1] Asphalt and Bituminous Rock Deposits, 1901, 316.

The Elk Asphalt Company has a similar sand of the following composition:

BITUMINOUS SAND FROM ELK ASPHALT COMPANY DEPOSIT, OKLAHOMA.

TEST No. 30483.

Bitumen soluble in CS_2	8.7%
Passing 200-mesh sieve	10.3
" 100- " "	7.0
" 80- " "	10.0
" 50- " "	34.0
" 40- " "	12.0
" 30- " "	4.0
" 20- " "	4.0
" 10- " "	6.0
Retained on 10-mesh sieve	4.0
	100.0

Character of extracted bitumen = ... Soft maltha.

From this sand a bitumen has been extracted having the following composition:

BITUMEN EXTRACTED FROM ELK ASPHALT COMPANY'S DEPOSIT OF BITUMINOUS SAND, OKLAHOMA.

TEST No. 30475.

Loss, 212° F., 1 hour	0.2%
Consistency of residue after heating	Too soft for penetration
DRY SUBSTANCE.	
Loss, 325° F., 7 hours	4.2%
Consistency of residue after heating	Too soft for penetration
Bitumen soluble in CS_2, air temperature	88.0%
Difference	3.1
Inorganic or mineral matter	8.9
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	79.1%
This is per cent of total bitumen	89.9
Bitumen soluble in 62° naphtha, air temperature	85.4%
This is per cent of total bitumen	96.6
Extracted bitumen	Too soft for penetration

Upon this material the same remarks may be made as in the case of the Sneider bitumen.

Near Emet, in the same neighborhood, bituminous sands are found which have the following characteristics:

DEPOSIT OF BITUMINOUS SAND NEAR EMET, OKLAHOMA

TEST NO. 30477.

Bitumen soluble in CS_2	10.4%
Passing 200-mesh sieve	2.6
" 100- " "	2.0
" 80- " "	5.0
" 50- " "	63.0
" 40- " "	16.0
" 30- " "	1.0
" 20- " "	0.0
" 10- " "	0.0
	100.0

Consistency of extracted bitumen = . . . Soft maltha

This sand, like the others, is impregnated with a soft maltha.

In the Quapaw Reservation a sand occurs which contains from 16 to 18 per cent of bitumen, the sand grains having the following grading:

BITUMINOUS SAND, QUAPAW RESERVATION, OKLAHOMA.

Test number	30479	30141
Bitumen soluble in CS_2	18.0%	16.5%
Passing 200-mesh sieve	29.0	37.3
" 100- " "	12.0	10.1
" 80- " "	4.0	5.0
" 50- " "	12.0	19.0
" 40- " "	7.0	10.0
" 30- " "	3.0	.7
" 20- " "	2.0	.7
" 10- " "	4.0	.7
Retained on 10-mesh sieve	9.0	.0
	100.0	100.0

This sand apparently contains some organic matter not of a bituminous nature.

Bituminous Limestone at Ravia.—Just south of the Washita River and Tishomingo, at Ravia, is a large deposit of bituminous limestone. This contains 7.1 per cent of bitumen with variations between 2.3 and 13.2 per cent. The bitumen is a rather dense maltha having a penetration of 210° on extraction. The limestone does not break down on extraction with solvents and in thin section under the microscope is shown to be of uneven texture containing crystals of calcite which are not impregnated with bitumen. The rock is not made up, as in the case of the Continental asphaltic limestones, of the remains of marine organisms. Owing to this fact and the small percentage of bitumen in the rock it can be of no commercial interest. Several samples from the face of the mine give the following results on analyses:

BITUMINOUS LIMESTONE FROM RAVIA, OKLAHOMA.

Test number	67316	67317	67318	67319	67320	67321
Bitumen by CS_2	10.8%	7.3%	7.0%	3.4%	9.9%	9.6%
Mineral matter insoluble in HCl	18.5	15.5	14.3	30.8	11.3	17.9
Mineral matter soluble in HCl	69.9	75.8	73.2	63.7	77.9	71.3
Difference	.8	1.4	5.5	2.1	.9	1.2
	100.0	100.0	100.0	100.0	100.0	100.0

The Ravia rock is typical of all American asphaltic limestones and for this reason it is hardly to be believed that any of them possess the same desirable features as those which are mined in Europe.

Other deposits in the Arbuckle Mountain region are of much the same character as those which have been described and are of no commercial interest.

Eldridge states that at Wheeler there is one of the largest oil seepages in the United States. The character of the maltha at this point is very much the same as that which has been extracted from the sandstone. It is, of course, impossible to collect it in sufficient quantity to be employed in the paving industry.

Five miles northwest of Ardmore a stratum of bituminous sandstone is found having a dip which is nearly vertical. Many attempts have been made to utilize this material by boiling it with water, but they have all been failures and have resulted in the loss of considerable capital in the same way that has been the case elsewhere in Oklahoma. The best of the rock available at this point has the following composition:

BITUMINOUS SANDSTONE NEAR ARDMORE, OKLAHOMA.

Test number	47443	47444
Bitumen soluble in CS_2	9.6%	11.8%
Passing 200-mesh sieve	12.4	1.2
" 100- " "	50.0	5.0
" 80- " "	25.0	16.0
" 50- " "	2.0	59.0
" 40- " "	1.0	6.0
" 30- " "	0.0	1.0
" 20- "	0.0	0.0
" 10- " "	0.0	0.0
	100.0	100.0

Penetration of extracted bitumen at 78° F. = 44°. Too soft for pen.

In the preparation of the bitumen by extraction it is impossible to remove all the fine material and the maltha is much hardened in the process of boiling out the water. A sample of the so-called refined material contained 77.8 per cent of bitumen which had a penetration of 75°.

Grahamite in Oklahoma.—There are several occurrences of grahamite in Oklahoma, the chief one being in what Eldridge has denominated the Tenmile Creek District. This has been described in detail under the heading "Grahamite."[1] At another point, near Loco, in Section 36, T.2.S., R.4.W., grahamite has been found in a network of veins which is remarkable as containing from 23.6 per cent to 2.4 per cent of pyrites, evidently introduced by infiltration. No commercial supply of this material is available.

Eldridge has classified these materials as "Asphaltites" and regards that found at the so-called Moulton mine as closely resembling albertite. He has named it Impsonite. The author sees no reason to use the word Asphaltite as applied to these bitumens as its original use was quite different. It is a fact that the weathered bitumen at the Moulton deposit on the surface resembles albertite to a considerable extent, being only slightly soluble in the ordinary solvents for bitumen. As the material has been taken out deeper down in the vein it is found to be entirely soluble in carbon disulphide, to yield a percentage of fixed carbon which is characteristic of grahamite and in every way to resemble closely the type grahamite originally described from Ritchie County, West Virginia. It cannot, therefore, be properly assigned a new name, Impsonite.

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[1] See page 211.

The Value of the Deposits of Oklahoma in Relation to the Paving Industry.—From what has been said in our description of the Oklahoma bituminous deposits it is evident that the only conclusion that can be drawn in regard to them is that they are of little industrial interest with the exception, perhaps, of the grahamite. The deposits, although large in amount, taken as a whole are individually small and moreover, far from being uniform in their character, they contain too little bitumen and this bitumen is not sufficiently asphaltic in its character. It is very improbable that any return will ever be obtained for the amount of money that has been spent in attempting to develop them.

Texas.—Bitumen is found in Texas impregnating limestone in Burnet and Uvalde Counties and mixed with sand in Montague County.

The latter deposits are near St. Jo. They are of no commercial interest and resemble in many respects those found in Oklahoma.

In Burnet County, Eldridge states, the deposit consists of Cretaceous limestones at Post Mountain, near the town of Burnet, which are impregnated with from 4 to 8 per cent of bitumen, mostly with the latter amount. The bitumen is soft and sticky, penetrating 240° on extraction. The quantity of asphalt bearing rock is stated to be limited.

In Uvalde County the bituminous material is found 18 to 25 miles west of Uvalde in the region of the Anacacho Mountains. The only deposit which has been worked to any considerable extent is a peculiar limestone which Eldridge described as being " an assemblage of minute organisms together with a conspicuous proportion of crystalline calcite. Molluscan remains, often of large size, are also present. Through the mass of rock there is a high per cent of interstitial spaces, which in some instances may even exceed the solid portions. In addition to the interstitial spaces, properly so-called, are cavities produced by the removal of the molluscan remains. . . ." The bitumen partially fills these cavities and also impregnates the limestone to a certain extent but the voids are never completely filled. On account of the nature of the rock and its great lack of homogeneity the material is not satisfactory for paving purposes, as is generally the case when calcite is present. The rock carries about 12 to 15 per cent of a peculiar bitumen, attempts to extract which were made at one time. Although it is now of no commercial value the character of the bitumen may be noted with interest.

Asphaltic Rock from Litho-Carbon Company.—An average sample of the rock, Test No. 7293, as worked, contained 12.8 per cent of bitumen, the mineral matter consisting of 87.0 per cent of limestone and 1.2 per cent of silicates insoluble in the acid. The bitumen extracted from this had the following characteristics:

ASPHALTIC ROCK FROM LITHO-CARBON COMPANY.

Softens	160° F.
Flows	170° F.
Per cent of bitumen soluble in 88° naphtha	54.5
Fixed carbon	18.0

ULTIMATE COMPOSITION.

Carbon	80.3%
Hydrogen	10.1
Sulphur	9.8

The character of this bitumen is quite different from that in asphalt found elsewhere owing to the fact that, notwithstanding its consistency, it has a high percentage of fixed carbon and contains a larger amount of sulphur than is found in any asphalt of the same consistency. On account of these peculiar properties it was known, at the time that an attempt was made to put it on the market, as Litho Carbon or Gum Asphalt. There is, of course, no reason to call it a gum, except from the fact that it might be employed as a substitute for some of the resins known as gums in the varnish trade. No native bitumen can possibly be regarded as a gum.

A fine grained bituminous limestone is also found on the Smythe Ranch, " about 20 miles a little south of west from Uvalde and 4 or 5 miles south of the quarry of the Uvalde Asphalt Company." It is quite different in character from that which has previously been described. A specimen of the material examined in the author's laboratory had the following characteristics:

BITUMINOUS LIMESTONE FROM SMYTHE RANCHE, TEXAS.

TEST NO. 22070.

Bitumen soluble in CS_2	12.2%
Limestone	87.8
Sand insoluble in HCl	1.2
	100.0

EXTRACTED BITUMEN.

Consistency	Hard–friable
Softens	240° F.
Flows	250° F.
Fixed carbon	16.9%

Bituminous sandstones are also found in Uvalde County and consist of an extremely fine sand, the larger portion passing the 100-mesh sieve, impregnated with a bitumen yielding a large amount of fixed carbon and, therefore, similar to that found in the limestone.

BITUMINOUS SANDSTONE, UVALDE COUNTY, TEXAS.

Test number	22071	22072
Bitumen soluble in CS_2	9.8%	8.1%
Sand	90.2	91.9
	100.0	100.0
Per cent of the sand insoluble in HCl	96.5%	93.6%
Per cent of the sand passing 100-mesh sieve	88.2%	91.9%

EXTRACTED BITUMEN.

Softens	210° F.	......
Flows	220° F.	......
Fixed carbon	19.5%	......

Bituminous Sands of California.—The location of the bituminous sands of California has been described in detail by Eldridge. It will suffice to remark here upon the character of some of the most important.

Santa Cruz Bituminous Sands.—The quarries of bituminous sand near the summit of the Empire Ridge, facing the Bay of Monterey and the Pacific Ocean, are of very large extent. The individual strata are very variable in composition, as can be seen from the results of an examination of the various types found there, collected by the author in 1898:

BITUMINOUS SANDS, SANTA CRUZ, CALIFORNIA.

Test No. 13578. Soft material from the foot of Point Quarry.
“ “ 13579. Top of stratum, Side Hill Quarry.
“ “ 13580. Richest rock, Side Hill Quarry.
“ “ 13581. Lowest stratum, Rattlesnake Quarry.
“ “ 13582. 6 to 9-foot vein, Hole Quarry.
“ “ 13583. Poorer rock, Hole Quarry.
“ “ 13584. Gray rock, Hole Quarry.
“ “ 13585. 6 to 9-foot vein, Last Chance Quarry.

Test number	13578	13579	13580	13581
Bitumen soluble in CS_2	14.4%	15.4%	13.2%	15.1%
Passing 200-mesh sieve	6.4	5.2	8.6	1.5
“ 100- “ “	2.2	3.4	5.2	7.4
“ 80- “ “	10.0	10.0	12.0	10.0
“ 50- “ “	29.0	30.0	40.0	35.0
“ 40- “ “	10.0	10.0	13.0	13.0
“ 30- “ “	15.0	17.0	5.0	10.0
“ 20- “ “	9.0	6.0	2.0	5.0
“ 10- “ “	4.0	3.0	1.0	3.0
	100.0	100.0	100.0	100.0

Test number	13582	13583	13584	13585
Bitumen soluble in CS_2	17.3%	11.4%	11.7%	14.2%
Passing 200-mesh sieve	5.6	1.5	4.7	2.4
“ 100- “ “	24.1	4.1	26.6	2.4
“ 80- “ “	39.0	12.0	33.0	6.0
“ 50- “ “	11.0	35.0	20.0	39.0
“ 40- “ “	3.0	20.0	3.0	18.0
“ 30- “ “	0.0	11.0	1.0	14.0
“ 20- “ “	0.0	4.0	0.0	4.0
“ 10 “ “	0.0	0.0	0.0	0.0
	100.0	100.0	100.0	100.0

The bitumen which these sands contain is in the form of maltha, much of it readily staining the hands when the sands are handled. It hardens on heating with a loss of the lighter oils and a reduction in the percentage of bitumen to a point which makes it possible to produce a surface mixture which will withstand traffic.

It will be noted that the grading of these sands is sufficiently fine and that they contain a certain amount of 200-mesh material.

The streets which have been paved with the Santa Cruz bituminous sands in San Francisco have been only fairly satisfactory. They have required large repairs which, however, are readily made by reheating the material, but there is now a tendency to abandon this form of asphalt pavement and to construct surfaces from properly graded sand combined with filler and a suitable pure bitumen.

San Luis Obispo Bituminous Sands.—Deposits of bituminous sands near San Luis Obispo, in the county of the same name, were formerly worked to a very considerable extent, but these sands were much more variable in character than those found at Santa Cruz. Different strata contain from 8 to 16 per cent of bitumen and generally below 10 per cent. The following analyses show the characteristics of those which were available in 1898:

BITUMINOUS SANDS, SAN LUIS OBISPO, CALIFORNIA.

Test number............	13576	13577
Bitumen soluble in CS_2...	8.8%	11.4%
Passing 200-mesh sieve...	11.9	4.4
" 100- " " ...	6.1	6.1
" 80- " " ...	10.2	16.1
" 50- " " ...	50.0	44.0
" 40- " " ...	8.0	9.6
" 30- " " ...	1.0	5.0
" 20- " " ...	1.0	3.0
" 10- " " ...	3.0	1.0
	100.0	100.0

The supply of the sands, which is readily available, is now nearly exhausted and they are no longer a commercial factor.

Bituminous Sands in Santa Barbara County.—Large deposits of bituminous sands occur in Santa Barbara County in the Sisquoc Hills, the location and geological relations of which are described by Eldridge.[1]

The deposit worked by the Alcatraz Company had the following composition:

SANTA BARBARA COUNTY, CALIFORNIA.

Test number	6484	6485
Bitumen soluble in CS_2	18.5%	16.5%
Passing 200-mesh sieve	12.5	7.5
" 100- " "	8.0	7.0
" 80- " "	3.0	6.0
" 50- " "	39.0	20.0
" 40- " "	10.0	20.0
" 30- " "	8.0	14.0
" 20- " "	1.0	8.0
" 10- " "	0.0	1.0
	100.0	100.0

This is a sand of medium grade, largely 50- and 40-mesh grains, but carries a very considerable amount of 200-mesh material. The bitumen is in the nature of a maltha and was extracted from the sand with naphtha, sent down to the seacoast by pipe-line and there recovered by distillation. On heating, the original soft bitumen was hardened to a proper consistency for use for paving purposes. The process proved to be an expensive one and the material when extracted was of no better quality than that obtained by the distillation of ordinary California petroleum. After the expenditure of a vast amount of money the process was abandoned.

Some of the bitumen prepared in this manner had the following characteristics:

BITUMEN EXTRACTED FROM SANTA BARBARA COUNTY, CALIFORNIA, BITUMINOUS SANDS.

TEST NO. 35202.

Penetration at 78° F.	48°
Bitumen soluble in CS_2, air temperature	89.4%
Difference	.3
Inorganic or mineral matter	10.3
	100.0

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[1] The Asphalt and Bituminous Rock Deposits, 1901, 429.

Carpinteria Sands.—One of the first bituminous sands to be worked in California for the purpose of obtaining a pure bitumen was that known as the Las Conchas deposit, occurring near the beach at Carpinteria, Santa Barbara County. The sand at this point was worked from the surface. It had the following composition:

LAS CONCHAS DEPOSIT AT CARPINTERIA, SANTA BARBARA, CALIFORNIA.

Test No. 6475.

Bitumen soluble in CS_2.	18.9%	18.4%
Passing 200-mesh sieve.	1.1	4.5
" 100- " "	3.0	3.0
" 80- " "	28.0	25.0
" 50- " "	45.2	48.0
" 40- " "	3.0	1.1
" 30- " "	.8	.0
	100.0	100.0
Per cent of total bitumen soluble in 88° naphtha. . . .	83.0%	

Attempts were made, which were never very successful practically or commercially, to extract the bitumen by boiling the sand with water. The material is of interest to-day only historically and as being typical of a certain class of soft bitumens the nature of which has been already referred to on page 128. They harden so on heating that a soft maltha will become converted into a brittle pitch most readily and on this account were the cause of the failures in the early attempts to lay asphalt surfaces with California material.

The deposits of solid bitumens in California have been considered under the heading " Asphalt."

Colorado.—The bitumens of Colorado consist only of a paraffine petroleum, in the Florence oil field, of some veins of gilsonite in the western portion, and of a grahamite found in Middle Park, the location and manner of occurrence of the latter being accurately described by Eldridge. He speaks of it as an asphalt closely resembling gilsonite which is, of course, quite an erroneous description as it does not melt and yields 47 per cent of fixed carbon. It has already been described under grahamite.[1]

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[1] See page 214.

The paraffine petroleum furnishes a flux which, when carefully prepared, is entirely satisfactory for use in the asphalt paving industry.

As far as the author is aware no asphaltic sands or limestones occur in Colorado which are of commercial importance.

The Gilsonites and Other Solid Native Bitumens of Utah.—Utah has deposits of bitumen of very varied character. Gilsonite veins are characteristic of this state and the material which they furnish has already been described. Wurtzilite and Ozocerite are found in small amounts but are of no importance to the paving industry, nor is the albertite which is found about eight miles from Helper Station on the Rio Grande & Western R.R., which Eldridge has unfortunately described under the new specific name of Nigrite, which is quite unnecessary and illustrates the duplication of names which is common among investigators who are not widely acquainted with the materials which they examine. It is plainly an albertite as can be seen from the following determinations in comparison with some for the type albertite found in Nova Scotia.

ALBERTITE.

Test number	19187	7834
Locality	Utah	Nova Scotia
Color of powder	Black	Black
Fracture	Irregular	Smooth
Fusibility	Does not intumesce	Intumesces slightly
Specific gravity, 78° F./78° F.	1.092	1.076
Bitumen soluble in CS_2, air temperature	5.6%	5.9%
Difference	94.2	94.1
Inorganic or mineral matter	.2	Trace
Bitumen yields on ignition:		
Fixed carbon	37.0%	29.8%
Sulphur	1.06%	1.2%

Wurtzilite might be a valuable material for industrial purposes were it available in commercial quantities, but this is not the case.

Ozocerite could never be of any value to the paving industry as it is a hard paraffine. The location of all these deposits are closely fixed by Eldridge.

Bituminous Sands and Limestones.—Asphaltic limestone is found in the same geological horizons as those in which the albertite and wurtzilite of Utah occur and its bitumen is probably of the same origin. That located by Eldridge between Strawberry and Soldier creeks, 7 miles northwest of Clear Creek Station, on the Rio G. & W. R.R., is far from uniform in composition, which has been found in the author's laboratory to be as follows:

ASPHALTIC LIMESTONE FROM NEAR CLEAR CREEK STATION, UTAH.

Test number	21633	21634	21635	21636
Bitumen soluble in CS_2	13.7%	13.3%	7.3%	5.2%
Penetration of extracted bitumen at 78° F.	10°	15°	7°	10°
Part soluble in HCl	62.3%	58.1%	52.9%	64.2%

The ignited residue effervesces with acid.

A limited supply of fairly pure bitumen has been obtained from this rock, which has the characteristics given in the table on page 249.

This is a most remarkable bitumen since there is such a great variation in the solubility in 88° and 62° naphthas and since it yields no fixed carbon on ignition. From a scientific point of view it is worthy of careful study.

Eldridge mentions deposits of asphaltic limestones in the same locality as that in which the wurtzilite veins occur along portions of the outer face of the Roan Plateau, on its westward extension, across Soldier Summit. These deposits have not been identified as any that have come into the author's hands.

In Grand County, near the western border of Colorado, at the head of the West Water Cañon, 20 miles north of West Water, free bitumen has been obtained to a certain extent, both in soft and hard form. This material when examined in the author's laboratory was found to have the characteristics given in the table on page 250, Test No. 60532.

BITUMEN EXTRACTED FROM LIMESTONE ROCK FOUND NEAR CLEAR CREEK STATION, UTAH.

TEST No. 21632.

Specific gravity, 78° F./78° F.	1.20
Color.	Light brown
Lustre	Dull shining
Structure.	Compact
Fracture.	Conchoidal
Hardness, original substance.	1
Fuses.	Readily
Softens.	210° F.
Flows.	220° F.
Loss, 212° F., 1 hour.	.6%
Bitumen soluble in CS_2, air temperature.	75.3%
Difference	3.4
Inorganic or mineral matter.	21.3
	100.0
Mineral matter soluble in HCl.	48.4%
Bitumen soluble in 88° naphtha, air temperature.	48.3%
This is per cent of total bitumen.	64.3
Bitumen soluble in 62° naphtha, air temperature.	72.8%
This is per cent of total bitumen.	96.7
Bitumen yields on ignition:	
Fixed carbon.	0.0%
Penetration of extracted bitumen at 78° F.	45°

From the small percentage of fixed carbon which the Grand County bitumen yields it is evident that it is not a true asphalt, that it approaches in composition more nearly that of the paraffine series, and resembles to some degree the material described from the locality near Clear Creek station.

The soft bitumen found at this point is a maltha which is very pure, 98.6 per cent of bitumen, which consists almost entirely of malthenes soluble in 88° naphtha, 94.5 per cent.

It has a specific gravity of .9874 and after heating for 7 hours at 325° F. hardens to a consistency of 53° and to 23° after the same length of time at 400° F.

These bitumens are of no commercial, but of great scientific interest as they differ so markedly in their characteristics from other asphalts. Gilsonite may have been derived from such a material.

BITUMEN FROM GRAND COUNTY, UTAH.

TEST NO. 60532.

DRIED CRUDE.

Bitumen soluble in CS_2, air temperature.......	43.2%
Difference	7.5
Inorganic or mineral matter................	49.3
	100.0

EXTRACTED BITUMEN.

Specific gravity, 78° F./78° F................	1.037
Color....................................	Black
Hardness.................................	Variable
Odor.....................................	Asphaltic
Softens..................................	203° F.
Flows....................................	221° F.
Penetration at 78° F......................	22°
Loss, 212° F., 1 hour......................	2.8 %
Bitumen soluble in CS_2, air temperature.......	94.8%
Difference	1.6
Inorganic or mineral matter................	3.6
	100.0
Bitumen soluble in 88° naphtha, air temperature	68.7%
This is per cent of total bitumen............	71.0
Bitumen soluble in 62° naphtha, air temperature	90.3%
This is per cent of total bitumen............	93.3
Bitumen yields on ignition:	
Fixed carbon............................	8.0%

Bituminous Sands.—Bituminous sandstones occur in various parts of Utah. The A. L. Hobson mine, 1½ miles from Thistle Junction, is a material of the following composition:

BITUMINOUS SAND FROM A. L. HOBSON MINE, THISTLE JUNCTION, UTAH.

TEST NO. 21730.

Loss, 212° F., until dry................	0.1%
Bitumen soluble in CS_2	11.6%
Part soluble in HCl....................	20.0

It appears that this is a mixture of sand and silicates.

About 8 miles from Sunnyside, in Carbon County, on the Rio G. &. W. R.R., a bituminous sand is found in large quantities which has the following composition:

BITUMINOUS SAND, SUNNYSIDE, CARBON COUNTY, UTAH.

Test No. 37048.

Bitumen soluble in CS_2	11.2%
Passing 200-mesh sieve	16.8
" 100- " "	17.0
" 80- " "	18.0
" 50- " "	26.0
" 40- " "	6.0
" 30- " "	2.0
" 20- " "	2.0
" 10- " "	1.0
	100.0
Mineral matter	Quartz sand
Extracted bitumen	Pulls to a thread

The mineral matter consists of quartz sand and the extracted bitumen possesses the characteristics of a maltha.

In Whitmore Cañon bituminous sandstone occurs nearly free from carbonates, the bitumen having a penetration of 35°. It has the following characteristics:

BITUMINOUS SAND, WHITMORE CAÑON, UTAH.

Test No. 21729.

Bitumen soluble in CS_2	10.9%
Passing 200-mesh sieve	17.9
" 100- " "	16.1
" 80- " "	16.1
" 50- " "	21.4
" 40- " "	14.2
" 30- " "	3.4
	100.0
Per cent soluble in HCl	2.6%
Extracted bitumen, penetration at 78° F. =	35°

The bitumen obtained from this sand is a maltha which has been examined by the author with the following results:

BITUMEN EXTRACTED FROM SAND FROM WHITMORE CAÑON, UTAH.

TEST NO. 21731.

Penetration at 78° F.	Too soft for test
Loss, 212° F., until dry	18.6%
Loss, 325° F., 7 hours	6.6%
Residue after 325° F. penetrates	145°
Bitumen soluble in CS_2, air temperature	97.8%
Difference	0.6
Inorganic or mineral matter	1.6
	100.0
Bitumen soluble in 88° naphtha, air temperature	89.8%
This is per cent of total bitumen	91.8
Bitumen soluble in 62° naphtha, air temperature	97.0%
This is per cent of total bitumen	98.7
Bitumen yields on ignition:	
Fixed carbon	5.0%

It is evident from the small amount of fixed carbon which it yields that it is not asphaltic and it, therefore, corresponds in this respect with the bitumen found in similar Utah bituminous sands and limestones previously described. It would seem, therefore that the bitumens of this nature found in Utah are more closely allied to ozocerite or to gilsonite than they are to the asphalts.

Deposits in Other States.—Seepages of maltha and sand and limestone impregnated therewith are found in many other States, the distribution of bitumen being much more general than would be supposed. None of these deposits are of any commercial interest and must, therefore, be passed over.

Continental Rock Asphalts.—The asphaltic limestones from the Continent of Europe, which have been the main source of the material for the asphalt paving industry in that country, are scattered through France, Switzerland, Germany, Sicily, and Italy. As these rocks reach the United States they have the composition given on pages 253 and 254.

CONTINENTAL ROCK ASPHALTS.

Test No. 47137. Ragusa, Sicily.
" " 47147. Seyssel, France.
" " 47153. Vorwohle.
" " 47156. Sicula, Sicily.
" " 47159. Neuchâtel, Val de Travers.
" " 47162. Mons.

Test number	47137	47147	47153	47156	47159	47162
Bitumen soluble in CS_2	9.9%	5.9%	7.5%	10.2%	9.1%	8.9%
Passing 200-mesh sieve	37.1	44.1	18.5	33.8	36.9	53.1
" 100- " "	17.0	10.0	14.0	16.0	14.0	9.0
" 80- " "	6.0	5.0	21.0	9.0	15.0	4.0
" 50- " "	14.0	9.0	25.0	18.0	14.0	7.0
" 40- " "	4.0	7.0	7.0	8.0	4.0	5.0
" 30- " "	2.0	7.0	2.0	3.0	4.0	3.0
" 20- " "	5.0	6.0	3.0	1.0	2.0	5.0
" 10- " "	5.0	6.0	2.0	1.0	1.0	5.0
	100.0	100.0	100.0	100.0	100.0	100.0

For some of the rocks which have not been examined by the author reference must be made to the analyses of others.[1] See the table on page 254.

These asphaltic limestones are characterized more by differences in the grain of the limestone than of their bitumen contents. As seen in thin sections it appears that the Continental asphaltic limestones consist of the remains of marine animal life, and it is undoubtedly this fact which gives them their uniform impregnation and their faculty of being readily compacted, as distinguished from American asphaltic limestones which contain very considerable proportions of hard crystalline calcite not impregnated with bitumen.

The Sicilian rock may vary in bitumen from 6.6 to 11.4 per cent. The rock exported by the Sicula Company is about as rich—3000 tons examined by the author, in three samples, containing 9.5, 9.3, and 9.9 per cent of bitumen, though some of it reaches 12 per cent. The Mons rock is not evenly impregnated; veins which are pure white being scattered through the material. This rock is used more on account of the character of the grain than for its bitumen contents, which will average 6.5 per cent to 9.0 per cent. The rock obtained from the Seyssel mine at present is very poor in bitumen, not exceeding 6 per cent and in some cases dropping to 1 per cent. It is used on account of the character of the grain of the stone.

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[1] Dietrich, Die Asphaltenstrassen.

CONTINENTAL ROCK ASPHALTS.

1. Val de Travers.	5. Cesi.
2. Seyssel, Pyrimont.	6. Roccamorice.
3. Lobsann.	7. Limmer.
4. Ragusa.	8. Vorwohle.

	1	2	3	4	5	6	7	8
Bitumen	10.15%	8.15%	12.32%	8.92%	7.15%	12.46%	14.30%	8.50%
Carbonate of lime	88.40	91.30	71.43	88.21	73.76	77.53	67.00	80.04
Sulphate of lime					1.72	2.63		
Alumina and iron oxides	0.25	0.15	5.91	0.91	3.02	2.17		4.03
Sulphur	.....	...	5.18		.....	.....	.....	
Carbonate of magnesia	0.30	0.10	0.31	0.96	14.24	4.71	17.52	0.55
Sand	...	.... .	3.15	0.60	0.10	0.50	.....	4.77
Insoluble in acid	0.45	0.10			.....	.....	.....	
Difference	0.45	0.20	1.70	0.40	.....	.....	1.18	2.11

The richer Sicilian rock by itself does not form a stable pavement but when some of the Seyssel or Mons rock is added to it stability is obtained.

Continental rock asphalts are now used in this country almost solely in mastics, the extreme slipperiness of the pavement made with them having proved so objectionable in comparison with the asphaltic sand pavements that the former are no longer tolerated.

SUMMARY.

The asphaltic sands and limestones of the United States have not been shown to be attractive to those interested in the construction of asphalt pavements. The asphaltic sands of Kentucky are too deficient in bitumen to make a satisfactory surface mixture and at the same time the character of the bitumen which they contain is altogether too oily. Successful surfaces have never been made with these materials unless they have been largely amended by the addition of a considerable amount of a harder bitumen and a proper proportion of filler.

The bituminous sands of California, although they have been used to a very considerable extent, are now known to give results which cannot compare favorably in any way with the artificial mixtures which have been laid along parallel streets. Their use for heavy traffic work will no doubt be soon abandoned.

The bituminous limestones and sands of Oklahoma occur in such small masses and pockets that their uniformity can never be guaranteed. In a few instances excellent street surfaces have been constructed from the mixed sands and limestones obtained near Dougherty, but the character of the asphaltic limestones is such that they can never be used in the same way as the Continental asphaltic limestones, owing to the structure of their mineral aggregate.

As a whole it is probable that more money has been lost in attempting to develop the asphaltic deposits described in this chapter than will ever be recovered by working them.

CHAPTER XIII.

RESIDUAL PITCHES, OR SOLID BITUMENS DERIVED FROM ASPHALTIC AND OTHER PETROLEUMS.

If the distillation of the asphaltic petroleums of California, of the semi-asphaltic petroleums of Texas, or even of Russian oil and some paraffine petroleums, is carried sufficiently far the residue on cooling will be found to be a solid bitumen, and from asphaltic oils of a more or less asphaltic nature. The properties of these solid bitumens and their availability for industrial purposes depend largely, of course on the nature of the petroleum from which they are derived, the care with which the distillation is conducted and the amount of cracking which has taken place in the process.

Residual Pitches from California Petroleum.—The residues from California petroleum have been used to a very considerable extent in the paving industry and are generally known as "D" grade asphalt or under some trade designation or brand, such as Diamond, Obispo, Acme, or Hercules.

They have been, usually, all more or less carelessly manufactured without laboratory control and consequently vary in character and consistency. As a rule they are by-products resulting from the recovery of distillates of different gravities from crude petroleum and are not prepared especially for paving purposes. That they are badly cracked in the process of manufacture, the oil often being heated as high as 900° F., appears from the fact that if the petroleum from which they are obtained is distilled or evaporated under such conditions that cracking will not occur, as much as 60 per cent of a hard residue will remain, as shown by the following figures obtained in the author's laboratory, as compared with 30 per cent by industrial methods.

RESIDUAL PITCH FROM CALIFORNIA PETROLEUM PREPARED IN THE LABORATORY.

Test No. 69209.

Loss, 212° F., to constant weight	2.8%
Loss, heating until 59° penetration is obtained	38.9%
Residual solid bitumen penetrating 59°	61.1
	100.0

ANALYSIS OF BITUMEN PENETRATING 59°.

Loss, 400° F., 4 hours	4.5%
Penetration of residue after heating	29°
Bitumen soluble in CS_2, air temperature	99.8%
Difference	.1
Inorganic or mineral matter	.1
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	77.6%
This is per cent of total bitumen	77.8%
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	0.5%
Bitumen yields on ignition:	
Fixed carbon	10.5%

As a matter of fact, under the conditions which obtain industrially, only 30 to 40 per cent of solid residue is recovered, the remainder being cracked and volatilized, and such residues contain a much larger amount of fixed carbon, 15 to 20 per cent, than is found on careful evaporation. With the form of still at present in use and with the most careful handling the temperature rises to 720° F. and the residual pitch is much smaller in amount, in the author's experience, than it should be. As an illustration of this, at an oil works under the author's observation, where an endeavor was made to produce the best "D" grade material for paving purposes, the petroleum in use, on careful evaporation at 400° F., left a residuum of solid bitumen amounting to 61.1 per cent, and penetrating 59°, as appears in the preceding table, whereas industrially only 33 per cent was recovered having about the same penetration. The physical characteristics and proximate composition of the industrial product obtained in this way are given in the accompanying tables. See pages 258, 259, 260, 261, and 262.

“D”-GRADE CALIFORNIA ASPHALT—PHYSICA

Test number	18250
Year received	1898
PHYSICAL PROPERTIES.	
Specific gravity 78° F./78° F., original substance, dry	1.089
Color of powder or streak	Black
Lustre	Lustrous
Structure	Uniform
Fracture	Conchoidal
Hardness, original substance	−1
Odor	Asphaltic
Softens	150° F.
Flows	162° F.
Penetration at 78° F.	25°
CHEMICAL CHARACTERISTICS.	
Loss, 325° F., 7 hours	.83%
Residue penetrates at 78° F.	17°
Loss, 400° F., 7 hours (fresh sample)	4.9%
Residue penetrates at 78° F.	9°
Bitumen soluble in CS_2, air temperature	98.3%
Difference	0.5
Inorganic or mineral matter	1.2
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	65.0%
This is per cent of total bitumen	68.6
Per cent of soluble bitumen removed by H_2SO_4	50.0
Per cent of total bitumen as saturated hydrocarbons	33.1
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	7.0
Bitumen yields on ignition:	
Fixed carbon	19.0%

It will be noted by a comparison of the above data with those given on page 257 that while the solubility of the bitumen in carbon disulphide is unaltered in the process of distillation a very considerable portion of it has often been rendered insoluble in cold carbon tetrachloride and in 88° naphtha. At the same time the amount of fixed carbon in the industrial product is largely

CHARACTERISTICS AND PROXIMATE COMPOSITION.

68488	69549	69550	69605	69606
1903	March 1904	March 1904	April 1904	April 1904
1.062	1.052	1.046	1.055	1.071
Black	Black	Black	Black	Black
Lustrous	Lustrous	Lustrous	Lustrous	Lustrous
Uniform	Uniform	Uniform	Uniform	Uniform
Sticky	Sticky	Sticky	Sticky	Conchoidal
Tacky	Tacky	Tacky	Tacky	–1
Asphaltic	Asphaltic	Asphaltic	Asphaltic	Asphaltic
142° F	178° F.	106° F.	128° F.	120° F.
156° F.	190° F.	120° F.	141° F.	135° F.
52°	45°	65°	50°	52°
83%	2.7%	.94%	2.1%	2.7%
Hard	Hard	33°	23°	29°
6.2%	9.6%	8.4%	6.7%	7.1%
Hard	Hard	8°	10°	16°
99.3%	99.2%	99.6%	99.6%	99.7%
.4	.8	.4	.3	.3
.3	Trace	.0	.1	Trace
100.0	100.0	100.0	100.0	100.0
77.0%	66.6%	70.5%	68.5%	70.0%
77.5	67.0	70.8	68.8	72.2
47.8	56.9	62.7	57.7	57.3
40.5	28.9	26.4	29.2	42.8
0.5%	7.3%	2.8%	2.2%	6.0%
15.0%	18.0%	16.7%	18.0%	18.8%

increased and this increase corresponds to the degree of severity of the heat to which the oil has been subjected. These differences characterize the California pitches as being, to a certain extent, products of decomposition and on this account undesirable material.

Considered as a class they are also undesirable because they

"D" GRADE CALIFORNIA ASPHALT.

Test number	18250	68488
	Carelessly Prepared	More Carefully Prepared
PHYSICAL PROPERTIES.		
Specific Gravity, 78° F./78° F., original substance, dry	1.089	1.062
Color of powder or streak	Black	Black
Lustre	Lustrous	Lustrous
Structure	Uniform	Uniform
Fracture	Conchoidal	Tacky
Hardness, original substance	−1	Sticky
Odor	Asphaltic	Asphaltic
Softens	150° F.	142° F.
Flows	162° F.	156° F.
Penetration at 78° F.	25°	52°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss, 325° F., 7 hours	.83%	.83%
Residue penetrates at 78° F	17°	Hard
Loss, 400° F., 7 hours (fresh sample)	4.9%	6.2%
Residue penetrates at 78° F	9°	Hard
Bitumen soluble in CS_2, air temperature	98.3%	99.3%
Difference	0.5	.4
Inorganic or mineral matter	1.2	.3
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temperature	65.0%	77.0%
This is per cent of total bitumen	68.6	77.5
Per cent of soluble bitumen removed by H_2SO_4	50.0	47.8
Per cent of total bitumen as saturated hydrocarbons	33.1	40.5
Bitumen soluble in 62° naphtha	....	80.2%
This is per cent of total bitumen	....	80.8
Carbenes:		
Per cent of bitumen insoluble in carbon tetrachloride, air temperature	7.0%	0.5%
Bitumen yields on ignition:		
Fixed carbon	19.0%	15.0%

are not uniform in character, as shown by the different degree of solubility of the bitumen in cold carbon tetrachloride and by the very considerable variation in the amount of fixed carbon which they yield.

"D" GRADE ASPHALT FROM REFINERY AT LOS ANGELES, CAL. AVERAGE AND EXTREMES OF COMPOSITION IN 1904.

	Average.	Highest.	Lowest.
PHYSICAL PROPERTIES.			
Specific gravity, 78° F./78° F., original substance, dry	1.060	1.066	1.054
Flashes, ° F., N. Y. State oil-tester	406° F.	420° F.	385° F.
Softens	137° F.	150° F.	124° F.
Flows	150° F.	180° F.	140° F.
Penetration at 78° F.	56°	118°	24°
CHEMICAL CHARACTERISTICS.			
Loss, 400° F., 4 hours	7.12%	9.40%	5.52%
Residue after heating penetrates at 78° F.	14°	15°	12°
Bitumen soluble in CS_2, air temperature	99.4%	99.9%	98.1%
Difference	.4	1.59	.0
Inorganic or mineral matter	.2	.54	.0
	100.0		
Malthenes: Per cent of total bitumen soluble in 88° naphtha, air temperature	71.61%	83.81%	66.01%
Carbenes: Insoluble in carbon tetrachloride, air temperature	4.37%	6.91%	.32%
Number of runs	565		

From an average of a very large number of analyses of "D" grade asphalts it has been found that the amount of fixed carbon which they yield, when prepared as carefully as possible by the present industrial process, does not vary far from 15 per cent, although at times it reaches 19 per cent where the product is carelessly handled, and should not exceed 10 per cent as shown by our laboratory results. This characteristic of the California pitches is important in differentiating them from those made from Texas oil, which yield a much higher percentage of fixed carbon.

"D" GRADE CALIFORNIA ASPHALT. BITUMEN INSOLUBLE IN CARBON TETRACHLORIDE.

Test Number.	Bitumen Insoluble in Carbon Tetrachloride, Air Temperature.
18250	7.0%
63847	.5
69549	7.3
73798	.6
73799	.4
73800	.3
73801	.1
73959	.2
73960	.1
73961	.1
73962	.2
74087	.2
74088	2.8
74089	.1
74090	.2
74091	1.3

For the purpose of preparing a pitch suitable for paving purposes it is, of course, desirable that some of the malthenes should be converted to asphaltenes, although not to carbenes. The bitumen, soluble in 88° naphtha, should be reduced to about 70–75 per cent and the fixed carbon should reach 15 per cent.

Harder Residual Pitches.—Where the consistency of the asphaltic residue is harder, its character has been denominated by other letters than " D." For example, A, B, and C grades are found, and much of the " D " grade put upon the market corresponds to these materials rather than to a true " D " grade. Where an attempt is made to manufacture the different grades they are expected to be of a consistency corresponding to the following penetrations on the Bowen scale:

A Grade	9°
B "	15°
C "	25°
D "	46° and above.

Residual bitumens having a penetration of less than 46° are deficient in the less viscous malthenes and require a very large amount of flux, to bring them to a proper consistency for paving cement. This results in the presence of too large a percentage of both brittle asphaltenes and the lighter forms of malthenes. Where these very hard residual pitches are in use in the production of a paving cement the results have been disastrous in climates where severe conditions are met, although they may be passable in the climate of Southern California.

Of late years, the use of such very hard residual pitches has been done away with, and those which are used for paving purposes are now very skilfully prepared at low temperatures, of very nearly the proper consistency for use as a paving cement, so that it is not necessary to add more than two or three pounds of flux, and often none at all, before using the bitumen.

"**Specifications for 'D' Grade Asphalt.**—'D' grade asphalt should be the residue from the careful distillation, with steam agitation, of some suitable California petroleum at as low a temperature as possible and certainly not exceeding 700° F. It shall be free from free carbon or suspended insoluble matter, which are evidences of excessive cracking.

"It shall be soluble to the extent of at least 98 per cent in carbon disulphide, 95 per cent in cold carbon tetrachloride and not less than 65 nor more than 80 per cent of it shall be soluble in 88° Pennsylvania naphtha, preferably nearer the former figure.

"It shall not flash below 450° F. and shall have a density between 1.04 and 1.06. It shall not volatilize more than 8.0 per cent at 400° F. in 4 hours, and shall have a penetration between 40° and 70°. It shall melt at not less than 140° nor over 180° F. on mercury, according to the method in use in the New York Testing Laboratory, and shall yield not more than 15 per cent of fixed carbon on ignition.

"It shall have a consistency of not less than four (4) millimeters penetration at 78° F. when tested for five (5) seconds with a No. 2 needle weighted with 100 grams."

The lower the temperature at which the asphalt is produced the smaller the percentage of cracked products it will contain and the smaller the loss will be on heating for 4 hours at 400° F.

The difference in its character when run down in 20 and 65 hours can be seen from the following figures:

COMPARISON BETWEEN "D" GRADE TAKING 65 AND 20 HOURS TO COME TO GRADE.

Hours to grade	20	65
Still	Small	Large
Bitumen soluble in CS_2, air temperature	99.65%	99.90%
Difference	.25	.10
Inorganic or mineral matter	.10	.00
	100.00	100.00
Malthenes:		
Bitumen solution in 88° naphtha, air temp	71.77%	72.50%
This is per cent of total bitumen	72.02	72.57
Penetration of still sample at 78° F.	70°	66°
" " barrelling sample at 78° F.	70°	69°
Specific gravity 78° F./78° F.	1.057	1.054
Softens	120° F.	124° F.
Flows	138° F.	140° F.
Loss, 400° F., 4 hours.	9.4%	6.8%
Penetration, at 78° F., of residue after heating	12°	15°
Yield	33.0%	43.5%

For comparison with the preceding "D" grade product a bitumen procured on the market in Los Angeles, Cal., in 1904, will serve. See table on page 265.

Here the percentage of fixed carbon is very high and that of the malthenes is low, the total bitumen at the same time amounting to only 93 per cent, while a very large proportion of bitumen soluble in carbon disulphide but insoluble in cold carbon tetrachloride and of free carbon are present. This material has been plainly overheated and it will require from 30 to 40 pounds of flux instead of the much smaller quantity necessary with a properly prepared asphalt. In this connection it may be of interest to remark that the hardness of a "D" grade asphalt is proportional, as in the native bitumens, to the percentage of naphtha soluble bitumen which it contains as appears from the following deter-

"D" GRADE ASPHALT FROM AN ASPHALTUM OIL AND REFINING CO.

PHYSICAL PROPERTIES.

Test number	69014
Specific gravity, 78° F./78° F., original substance, dry	1.077
Softens	195° F.
Flows	205° F.
Penetration at 78° F.	27°

CHEMICAL CHARACTERISTICS.

Original substance:	
Loss, 212° F., 1 hour	0.0%
Dry substance:	
Loss, 325° F., 7 hours	1.3%
Character of residue	Surface smooth.
Loss, 400° F., 7 hours, additional loss	5.3%
Character of residue	Shrivelled surface, penetration 5°.
Bitumen soluble in CS_2, air temperature	92.6%
Difference (largely carbon)	7.3
Inorganic or mineral matter	.1
	100.0
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	64.4%
This is per cent of total bitumen	69.5
Bitumen soluble in 62° naphtha	65.6%
This is per cent of total bitumen	70.8
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	13.1%
Bitumen yields on ignition:	
Fixed carbon	19.0%

REMARKS: A small amount of suspended matter is noted under the microscope.

minations on the products produced at one plant under the same conditions:

Number	103	104	105	106
Penetration at 78° F.	31°	53°	54°	87°
Naphtha soluble bitumen	66.0%	70.6%	70.6%	72.4%

Asphaltic Residues from Texas Oil.—The semi-asphaltic oil from the Beaumont field in Texas leaves a residue of solid bitumen on distillation which, however, as in the case of California oil, varies in character according to the method of distillation employed. In the case of California oils, with careful distillation a larger percentage of residue was obtained than was the case industrially. With the Beaumont oil the reverse is the case; on distillation in vacuo but 9.0 per cent of solid bitumen was recovered while industrially as much as 30 per cent is obtained. This is, probably, due to the fact that condensation goes on in the case of the Beaumont oil instead of cracking as in the case of California petroleum. Analyses of residual pitches from Texas petroleum representing the product as turned out in 1903 and again in 1907, are given on the opposite page, the two materials originating from different manufacturers.

An examination of the preceding results shows that the distillation has been carried much further than is the case in the production of the California asphalts. This is evidenced by the greater density of the product and the very much higher percentage of fixed carbon which it yields. It should also be noted that the two forms of residual pitch are differentiated by the fact that that from the Texas oil contains a larger percentage of saturated hydrocarbons than that from the California oil, a fact which might be expected as the stability of the former is much greater than that of the latter, owing to the amount of paraffine hydrocarbons which it contains. The asphaltic residue from the Texas oil is marked by the presence of a little over 1 per cent of paraffine scale, but the amount is insufficient to give it the character of a paraffine material.

The residual pitches from Texas oil are no more uniform in

RESIDUAL PITCH FROM TEXAS PETROLEUM.

Test number	1903 68943	1907 102529
PHYSICAL PROPERTIES.		
Specific gravity, 78° F./78° F., original substance, dry	1.0803	1.0703
Color of powder or streak	Black	Black
Lustre	Lustrous	Lustrous
Structure	Uniform	Uniform
Fracture	Semi-conchoidal	Conchoidal
Hardness, original substance	−1	−1
Odor	Asphaltic	Petroleum
Softens	230° F.	143° F.
Flows	247° F.	164° F.
Penetration at 78° F., Bowen	13°	18°
Penetrometer at 78° F.	...	7°
CHEMICAL CHARACTERISTICS.		
Dry substance:		
Loss 325° F., 7 hours	.13%	.95%
Loss 400° F., 7 hours	.19	1.22
Bitumen soluble in CS_2, air temperature	99.0%	98.2%
Inorganic or mineral matter	.2	Trace
Difference	.8	1.8
	100.0	100.0
Malthenes:		
Bitumen soluble in 88° naphtha, air temp.	65.4%	69.6%
This is per cent of total bitumen	66.1	70.9
Per cent of soluble bitumen removed by H_2SO_4	32.1	51.1
Per cent of total bitumen as saturated hydrocarbons	44.8	65.6
Bitumen soluble in 62° naphtha	71.5%	70.1%
This is per cent of total bitumen	72.2	71.4
Carbenes:		
Bitumen insoluble in carbon tetrachloride, air temperature	5.1%	14.6%
Bitumen yields on ignition:		
Fixed carbon	24.0%	19.5%
Paraffine scale	1.2%	.8%

character than those prepared from California petroleum and, no doubt, for the same reason. That they are very variable in character can be seen from the results of an examination of five samples, taken from one delivery, which were submitted to the author for examination.

RESIDUAL PITCH FROM BEAUMONT, TEXAS, PETROLEUM TAKEN FROM ONE DELIVERY.

Test number	72550	72589	72590	72591	72592
Penetration at 78° F./78° F.	10°	16°	93°	58°	81°
Flow	None	None	100.0%	76.0%	86.0%
Bitumen soluble in CS_2	98.1%	97.7%	99.3	99.0	99.1
Difference	1.8	2.2	.4	.9	.5
Inorganic or mineral matter	.1	.1	.3	.1	.4
	100.0	100.0	100.0	100.0	100.0
Carbenes:					
Bitumen insoluble in carbon tetrachloride, air temperature.	10.5%	12.7%	6.7%	7.0%	6.7%
Bitumen yields on ignition:					
Fixed carbon	.....	23.0%			

In this delivery material was found which was so hard as to hardly flow at 212° F. (No. 72550) and so soft as to be readily melted (No. 72590).

Other lots which have been examined by the author have shown an equal lack of uniformity, as can be seen from the following figures:

RESIDUAL PITCH FROM BEAUMONT, TEXAS, PETROLEUM.

Test number	63526	63527	63528
Penetration at 78° F./78° F.	Too soft	110°	15°
Bitumen soluble in CS_2, air temperature	98.3%	96.6%	95.7%
Malthenes:			
Bitumen soluble in 88° naphtha, air temperature	78.2%	72.2%	67.9%
This is per cent of total bitumen	79.6	74.7	71.0
Carbenes:			
Bitumen insoluble in carbon tetrachloride, air temperature	8.6%	12.8%	12.5%
Bitumen yields on ignition:			
Fixed carbon	14.5%	17.6%	21.1%

The most important characteristic of the residual pitches from Texas oil is that they yield, as prepared, and as found on the market, more than 20 per cent of fixed carbon as compared with 15 per cent for the California pitches. This characteristic while it may be due somewhat to the fact that the Texas pitch is a denser material, because the distillation has been carried to a point beyond that to which the California oil is submitted, is an important one industrially as it makes it possible to differentiate and determine the origin of any of these forms of bitumen. The two can also be differentiated by determining whether paraffine is present, none being found in the California products and about 1 per cent in those from Texas.

Examples of the variation in the character of Texas residual pitches as revealed by the percentage of carbenes which they contain is shown by the following analyses:

RESIDUAL PITCHES FROM BEAUMONT, TEXAS, PETROLEUM.

Test Number.	Bitumen Insoluble in Carbon Tetrachloride, Air Temperature.
63526	8.6%
63527	12.8
63528	12.5
68943	5.1
69015	5.1
72550	10.5
72589	12.7
72590	6.7
72591	7.0
72592	6.7

The amount is generally much larger than is found in the more carefully prepared California "D" grade asphalt and points to overheating in the preparation of these particular specimens. This is much greater in the pitch which has been produced in 1907 than in the supply of 1903. The material has recently been of very poor quality, and, in the opinion of the author, it is entirely unsuitable for use in the paving industry.

Ebano Asphalt.—A residual pitch made from the asphaltic oil or maltha occurring at Ebano, Mexico, about thirty miles from Tampico, on the line of the Mexican Central Railroad, has been on the market in the United States and abroad, for a few years, under the designation of "Ebano Asphalt," a well sunk at that point to a depth of 1600 feet, producing from 1200 to 1500 barrels of petroleum a day. It corresponds in its preparation and characteristics to the California residual pitches. Following are the results of examinations of various grades of the material:

Test number	102261	102262	102263	102264
Identified as	"E"	"DX"	"D"	"B"
PHYSICAL PROPERTIES.				
Penetration at 78° F.—Bowen	62	30	26	7
Softens	125° F.	185° F.	190° F.	260° F.
Flows	163° F.	200° F.	206° F.	278° F.
CHEMICAL CHARACTERISTICS.				
Bitumen soluble in CS$_2$, air temp.	99.4%	97.9%	97.8%	95.8%
Inorganic or mineral matter	.1	.2	none	.3
Difference	.5	1.9	2.2	3.9
	100.0%	100.0%	100.0%	100.0%
Carbenes:				
Bitumen insoluble in carbon tetrachloride, air temperature	.4%	14.4%	15.5%	19.7%
Malthenes:				
Bitumen soluble in 88° naphtha, air temperature	69.0%	66.0%	55.5%	48.1%
This is per cent of total bitumen	69.4	66.5	56.3	50.2
Per cent of soluble bitumen removed by H$_2$SO$_4$	89.0	91.0	92.0	93.0
Bitumen yields on ignition:				
Fixed carbon	19.2%	23.9%	24.9%	30.5%
Paraffine scale	1.0%	1.3%	1.3%	1.9%

Where the Ebano asphalt is made of "E" grade consistency, it seems to be of a character as good as that of the same material made in California, but where the distillation has been carried to such a point that the consistency is much harder, the percentage of carbenes present shows that the bitumen has been, at least in some cases, very seriously decomposed and such a product is, on this account, very unsatisfactory.

Baku Pitch.—On the Continent a residual pitch from the distillation of Russian petroleum is an industrial product. This has the following composition:

BAKU PITCH.

Test number	63200

PHYSICAL PROPERTIES.

Specific gravity, 78° F./78° F., original substance, dry	1.1098
Color of powder or streak	Black
Lustre	Lustrous
Structure	Uniform
Fracture	Semi-conchoidal
Hardness, original substance	−1
Odor	Petroleum
Softens	140° F.
Flows	150° F.
Penetration at 78° F.	10°

CHEMICAL CHARACTERISTICS.

Bitumen soluble in CS_2, air temperature	91.6%
Difference	8.4
Inorganic or mineral matter	Trace
	100.0
Malthenes:	
Bitumen soluble in 88° naptha, air temperature	54.6%
This is per cent of total bitumen	59.6
Per cent of soluble bitumen removed by H_2SO_4	44.1
Per cent of total bitumen as saturated hydrocarbons	33.3
Bitumen soluble in 62° naphtha	61.3%
This is per cent of total bitumen	66.9
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temp	10.4%
Bitumen yields on ignition:	
Fixed carbon	26.8%
Paraffine scale	1.7%

This pitch has a comparatively high density, yields a large percentage of fixed carbon, bitumen insoluble in cold carbon tetrachloride and much organic matter not bitumen; showing that the distillation has been pushed to an extreme. It contains 1.7 per cent of paraffine scale. It is a remarkable fact that the softening-point of this material is much nearer that of the California residue than of that from Beaumont, Texas, oil. It might, perhaps, be possible to use a small amount of this bitumen in the paving industry as an amendment to some asphalts.

Solid Bitumens the Product of the Condensation of Heavy Oils.—Another class of bitumens are the artificial ones obtained by the treatment of any of the fluxes which have been described with sulphur or oxygen at high temperatures. In their uses and consistency they may be ranked between the fluxes and the solid bitumens.

Pittsburg Flux.—The first bitumen of this description to be put upon the market was known as Pittsburg Flux. It was made by adding to an ordinary Pennsylvania petroleum residuum about one pound of sulphur to every gallon of oil and heating the material to a point a little below that of distillation and maintaining it at that temperature until the evolution of hydrogen sulphide ceases. The residuum is, in this way converted into a semi-solid cheesy bitumen which is very short, that is to say, has little ductility, and is very slightly susceptible to changes of temperature. The reaction which takes place is represented by the following equation:

$$C_nH_{2n}+S=C_nH_{n-2}+H_2S.$$

The reaction, in reality, is not as simple as this but the result is explained as well. Two molecules are condensed to one with the accompanying evolution of hydrogen sulphide gas and with the resulting changes in the properties of the bitumen. The great expense incurred for sulphur in this process made it necessary to utilize the by-product of hydrogen sulphide. This was done by converting it into sulphuric acid. The business was not profitable even under these conditions and was soon abandoned. The material could not be used as the principal source of bitumen in making an asphalt cement, being too short, and only as an addition, in small amounts, to the ordinary asphalts. Used in this way it has been successful in one or two instances.

An analysis of this material is presented in the table on page 275.

Ventura Flux.—Later on an attempt was made to make a similar substance from the asphaltic petroleum of California. The product was a slight improvement on the Pittsburg Flux but pavements made with it without the addition of native solid bitumen were failures in Allegheny, Pa. Its manufacture was abandoned after a few years.

Byerlyte.—In the meantime Byerly, of Cleveland, had found that the oxygen of the air was as satisfactory a condensing agent as sulphur, imitating the practice of blowing certain vegetable and fish oils in order to thicken them and give them greater viscosity. He produced a substance similar to Pittsburg Flux by drawing air through residuum while the latter was maintained at a high temperature. Depending on the length of time during which the air was allowed to act the product was soft or as hard as pitch. This material has been used to some extent in making asphalt blocks in Washington, but even this use has now been abandoned. In mixture in small proportion with the native solid bitumens it can be used but there is no advantage in doing so commensurate with the expense involved in the treatment of the original residuum.

Hydroline "B."—Still more recently the asphaltic residuum from the asphaltic petroleums of Texas has been put upon the market, after having been blown, under the name Hydroline "B." It possesses in this form no qualities which could recommend it very strongly for paving purposes except, perhaps, as an amendment to certain inferior asphalts and it need hardly be considered here.

Sarco Asphalt.—This material, which has recently been on the market, is a blown product like Hydroline "B," prepared from Kansas residuum, and it possesses much the same properties, having little ductility and being very short.

A specimen recently examined in the author's laboratory, showed the following characteristics:

Test number	96891
PHYSICAL PROPERTIES.	
Specific gravity, 78° F./78° F., original substance, dry	.981
Softens	190° F.
Flows	210° F.
Penetration at 78° F.—Bowen	120°
Condition at 140° F. after 1 hour	Softens slightly.

CHEMICAL CHARACTERISTICS.

Bitumen soluble in CS_2, air temperature	99.1%
Inorganic or mineral matter	.7
Difference	.2
	100.0%
Malthenes:	
Bitumen soluble in 88° naphtha, air temperature	69.8%
This is per cent of total bitumen	70.4
Carbenes:	
Bitumen insoluble in carbon tetrachloride, air temperature	.2%
Bitumen yields on ignition:	
Fixed carbon	10.3%
Paraffine scale	12.3%

It is notable for the very high percentage of paraffine scale which it contains, which, in addition to the properties conferred by blowing the oil with air, adds to its shortness. It is made of several grades, having a penetration of from 50 to that of the sample which was examined.

According to analyses made by Mr. Francis P. Smith, three specimens which he examined had the following properties:

Test number	1175	1176	1210
Melting-point, degrees F.	171	188	198
Penetration at 32° F. (Dow, 1 min., 200 gms.)	42	49	31
Penetration at 77° F. (Dow, 5 sec., 100 gms.)	60	70	45
Penetration at 115° F. (Dow, 5 sec., 50 gms.)	97	85	71
Bitumen soluble in CS_2	98.0%	97.7%	98.7%
Organic insoluble	1.0	1.8	1.3
Ash	1.0	.5	Trace
Naphtha soluble bitumen	79.9%	79.0%	79.2%
Naphtha soluble bitumen (per cent total bit.)	81.5	80.9	80.3
Loss on heating 5 hours at 325° F.	.08%	.4%	.15%
Penetration after heating	60	61	33
Ductility	3 cm.	3 cm.	2 cm.
Fixed carbon	10.6%	10.8%	10.8%

It is hardly possible that a satisfactory pavement could be made with such material, although it might be combined to a certain extent with the ordinary asphalts.

The character of Pittsburg Flux, Byerlyte and Hydroline "B" is shown in the table on page 275.

From these figures it appears that the materials are nearly pure bitumens and that, not having been subjected to sufficiently high temperatures to produce cracking, the amount of bitumen insoluble in carbon tetrachloride is practically nothing. According to their derivation the materials carry more or less paraffine but the Hydroline " B " being derived from a Texas oil

Test number	.....	6123	6124	71436
Bitumen	Pittsburg Flux	Byerlyte (paving)	Byerlyte (roofing)	Hydroline "B".
PHYSICAL PROPERTIES.				
Specific gravity, 78° F./78° F., original substance, dry	.9879	1.023	.9070	1.0043
Color of powder or streak	Black	Black	Black	Black
Lustre	Dull	Dull	Dull	Dull
Structure	Uniform	Uniform	Uniform	Uniform
Fracture	Cheesy	Cheesy	Cheesy	Cheesy
Odor	Petroleum	Petroleum	Petroleum	Petroleum
Softens	295° F.	245° F.	230° F.	206° F.
Flows	353° F.	294° F.	254° F.	220° F.
Penetration at 78° F.	74°	63°	107°	55°
CHEMICAL CHARACTERISTICS.				
Dry substance:				
Loss, 325° F., 7 hours	1.7%	.93%	1.8%	1.0%
Character of residue	Smooth	Smooth	Smooth	Smooth penetration, 45°
Loss, 400° F., 7 hours (fresh sample)	4.4%	5.9%	6.5%	5.8%
Character of residue	Blistered	Smooth	Smooth	Smooth penetration, 40°
Bitumen soluble in CS_2, air temp.	99.7%	99.7%	99.5%	99.9%
Difference	.3	.3	.5	.1
Inorganic or mineral matter	.0	.0	.0	.0
	100.0	100.0	100.0	100.0
Malthenes:				
Bitumen soluble in 88° naphtha, air temperature	67.1%	62.0%	66.8%	69.3%
This is per cent of total bitumen.	67.3	62.2	67.1	69.4
Per cent of soluble bitumen removed by H_2SO_4	14.8	25.5	17.4	12.7
Per cent of total bitumen as saturated hydrocarbons	57.3	46.3	55.5	60.6
Bitumen soluble in 62° naphtha	71.5%	67.2%	72.0%	
This is per cent of total bitumen.	71.7	67.4	72.3	
Carbenes:				
Bitumen insoluble in carbon tetrachloride, air temperature	.3%	.4%	.3%	.5%
Bitumen yields on ignition:				
Fixed carbon	14.7%	18.0%	14.3%	12.2%
Paraffine scale	10.3%	4.6%	5.7%	1.0%

contains no more than is found in the residual pitch from the same oil. It is worthy of remark as to Byerlyte that, although made from paraffine oil, it contains much less paraffine scale than would be expected, and would point to the fact that this material has become altered in the process of manufacture.

With none of these materials, as the principal constituent of a paving cement, is it possible to produce a satisfactory surface mixture. They are all too short, but they may be used as an amendment in an amount not exceeding 10 per cent. Owing to the fact of their great lack of susceptibility to change in consistency within wide ranges of temperature they present some advantages.

Differentiation of the Residual Pitches from the Natural Asphalts.—The residual pitches, it appears from the preceding data, contain practically no mineral matter. With only one exception there is no native bitumen in use in the asphalt paving industry which has the same characteristic. It is, therefore, possible to differentiate, except in the case of gilsonite, an oil asphalt, so-called, from a native bitumen by determining the amount of mineral matter present. The mineral matter in the latter is generally of a ferruginous nature while that derived from the native bitumens generally contains silica. A microscopic examination of the residue left on ignition will, therefore, aid in the determination. Even in the case of gilsonite the color of the ash is quite different from that obtained from the residual pitches. Unfortunately the amount of fixed carbon which the California "D" grade asphalt yields and that from the native bitumens is so nearly the same that this characteristic cannot be successfully used, although the amount obtained may be of value as indicating the presence of grahamite which in itself has a high fixed carbon. The native bitumens carry, however, less bitumen insoluble in cold carbon tetrachloride but soluble in carbon disulphide than the residual pitches, unless the latter are very carefully made, and in case of doubt the differentiations of the two classes of materials may be assisted by comparative determinations of this form of bitumen.

SUMMARY.

All petroleums on evaporation under suitable conditions leave a pitchy residue. The residue from the asphaltic or semi-asphaltic petroleums resembles the native asphalts. The principal supplies available for use in the paving industry are residual pitches from California and from Texas oil. These are each made in such a careless way that they consist largely of alteration products of the original hydrocarbons as shown by the lack of solubility of some of their constituents as compared with those found in the original oil. On this account the material is not always satisfactory and, moreover, requires great skill to use it.

The residual pitches from Texas and from California oils can be readily differentiated by certain characteristics, that from the Texas oil generally yielding a higher percentage of fixed carbon than the pitch obtained from the California oil.

The blown or oxidized petroleum residues are characterized by their lack of susceptibility to temperature changes, but are extremely short, which prevents their use as the main source of bitumen in the paving mixture. Pavements laid with them have generally eventually proved failures. They may possess some desirable qualities as an amendment to the native asphalt to an extent not exceeding 10 per cent, and, used in this way, should be considered as fluxes.

CHAPTER XIV.

COMPARISON OF VARIOUS NATIVE ASPHALTS AND THEIR RELATIVE MERITS FOR PAVING PURPOSES.

In attempting to form an opinion on the availability of any native bitumen for paving purposes a number of things must be taken into consideration, which may be tabulated as follows:

1. The quantity available.
2. Its uniformity in character.
3. Its stability in a melted condition at high temperatures.
4. Its stability in consistency at the extremes of temperature which it meets in an asphalt pavement.
5. The proportion of malthenes to asphaltenes which it contains.
6. The proportion of flux which is required to make an asphalt cement.
7. Mineral matter present and its character.

1. **The Quantity Available.**—No native bitumen can be of any great importance in the paving industry without a large supply of it is available. Pavements can no doubt be constructed of a bitumen of which not more than 500 to 1000 tons can be gathered together with difficulty in any one year, but such supplies are too unreliable to permit of their being of permanent interest. There are hundreds of such deposits in which many thousands of dollars have been sunk without any adequate return for the investment. A deposit to be of any great value should afford a supply of at least 50,000 tons annually without difficulty. The first thing to be done, therefore, in considering the availability of native bitumen is to learn whether the deposit is such that the amount which

can be obtained from it will prove large enough to be of industrial importance.

2. **Its Uniformity in Character.**—A great consideration in the turning out of a regular asphalt surface mixture is that the bitumen from which it is made shall be of such a nature that every cargo or shipment of it may be exactly like all others. If this is not the case each lot will, of necessity, require a different method of handling, which necessitates great experience and skill which are not always to be found among those who are engaged in the laying of asphalt pavements.

3. **Its Stability in a Melted Condition at High Temperatures.**—As the asphalt cement made from the native bitumens as they occur in the refined condition in the trade is necessarily maintained in a melted condition at high temperature for considerable periods of time it is equally important that it should consist of a bitumen which does not become changed in consistency, under these conditions, owing to the rapid volatilization of certain of its constituents.

There is a very decided difference in the behavior of different bitumens in this respect and this should be borne in mind in determining whether one has a preference over another for use in the construction of asphalt pavements.

4. **Its Stability in Consistency at the Extremes of Temperature which it Meets in an Asphalt Pavement.**—There is a difference in the behavior of different bitumens, as far as their consistency is concerned, at the extremes of temperature which are met with in summer and winter, that is to say, some of them are much more susceptible to changes in consistency between very low and very high temperatures than others. This is an important consideration since, although a given bitumen may enable one to construct an asphalt surface which is of proper consistency at medium temperature, say 78° F., it may become extremely hard and brittle at zero or extremely soft and oily at 120° F., a temperature which asphalt surfaces frequently reach under our hot summer sun.

5. **The Proportion of Malthenes to Asphaltenes which it Contains.**—The relative proportion of malthenes, those constitutents which are soluble in light petroleum naphtha, and of asphaltenes,

the other constituents not soluble in this medium, has a bearing upon the availability of any native bitumen for paving purposes. Although to-day the deficiencies in this respect may be modified by the use of certain fluxes, which supply the missing constituents, this is not always the case and, when it is so, it requires very considerable skill to accomplish it. This has been illustrated more fully in another place.[1]

6. The Proportion of Flux which is Required to Make an Asphalt Cement.—The question of the amount of flux which is necessary to use with any bitumen is one of importance. If the native bitumen is so hard as to require a very large percentage of flux there is a very great probability, although this is not universally the case, that the resulting cement will be too oily and too susceptible to high temperature.

Gilsonite is a bitumen which is an exception to this rule. To flux this material in making an asphalt cement, about equal parts of it and of heavy asphaltic oil are necessary, but the cement contains normal proportions of malthenes soluble in 88° naphtha, and of asphaltenes insoluble. Such a cement has an extremely rubbery consistency and a considerable amount of elasticity, a cylinder of the cement springing back to its original formation when bent nearly double. Such a cement, in addition, is not as susceptible to temperature changes as those made from the ordinary asphalts. A statement in regard to the relative proportions of various fluxes which must be combined with the various asphalts to produce cements of different penetrations is given on page 308.

7. Mineral Matter Present and its Character.—The mineral matter present in any native bitumen may be desirable or undesirable. If it contains so much or if it is so coarse as to render it impossible to maintain it uniformly in suspension in the melted asphalt cement which is prepared from the bitumen it is undesirable. If, on the other hand, it is extremely fine and acts as a filler, as in the case of Trinidad asphalt, it is very desirable.

The fact that it may reduce the percentage of bitumen present is of no importance, since in the case of an asphalt consisting of

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[1] See pages 139 and 178.

99 per cent of bitumen it will be necessary in building up a satisfactory surface mixture to add a certain amount of filler which cannot be done as successfully by any artificial means as is done by nature.

In this connection the following correspondence between the President of the Board of Public Works of a western city and a local chemist, many years ago, may prove of interest as well as the latter's answers to several other questions which are frequently asked.

"May 22, 1893.

"Dear Sirs:—A discussion has been going on in this city, which the citizens are largely interested in, in regard to asphalt paving.

"It is claimed on one hand that asphalt is asphalt, no matter where it is found, and the only difference in asphalts is in the amount of bitumen which they contain. As a well-known and practical chemist in this city, I would thank you to answer the following questions, and send me a bill for your expert opinion.

"1. Does the percentage of bitumen determine the value of an asphalt for paving purposes?

"2. May or may not an asphalt contain a very large percentage of bitumen and still be worthless for paving purposes?

"3. Might or might not an asphalt, which in its natural state is good for paving purposes, be so destroyed by heat that it is practically worthless for paving purposes, and still the material after subjection to heat, be asphalt?

"4. Might or might not two asphalts contain the same amount of bitumen, and one be so unstable that it will not stand exposure to the sun, and the other be comparatively permanent?

"5. Is it possible that one asphalt might contain twice as much bitumen as another, and still be far inferior for street construction to the one containing a less quantity?

"6. Is there any real system by which a chemist can tell to a certainty, by analysis, whether a given asphalt which has never been tried will make as good, permanent, and durable a pavement as another which has proved a success?

"7. Are there or are there not qualities required of an asphalt for paving purposes which makes it impossible for a chemist who has not made the subject a special study, to state for a certainty whether a given untried asphalt will make as good a pavement as another asphalt which has proved a success?

"8. What is the real test of standard or quality which will give the value of an asphalt for paving purposes?

"9. Might an asphalt pavement stand for one or two years, and fail from effect of elements in succeeding years, and might two asphalts stand equally for two years and show marked differences in wear in succeeding years?

"An early reply will oblige,

"Yours respectfully,

(Signed) "PRESIDENT BOARD OF PUBLIC WORKS."

In reply to the above questions the following opinion was rendered:

"1st Answer. The percentage of bitumen does not determine the value of an asphalt for paving purposes.

"2d Answer. An asphalt might contain a very large percentage of bitumen, and still be comparatively worthless for paving purposes.

"3d Answer. An originally good asphalt for paving purposes might be so altered by heat as to be practically worthless, and yet the altered material would still be asphalt in the sense that it could not be distinguished from asphalt, notwithstanding its marked inferiority to the particular asphalt from which it was produced.

"4th Answer. Two asphalts might contain the same amounts of bitumen and yet possess entirely different powers of resistance to the destructive action of the elements. One might thus be comparatively permanent and stable, and the other greatly inferior.

"5th Answer. As the percentage of bitumen in an asphalt does not determine its value for paving purposes, it is quite possible for one asphalt to contain a much higher percentage than another and yet be decidedly inferior for making a durable pavement.

"6th Answer. There is no system of chemical analysis that will determine for a certainty that a given untried sample of asphalt will make, in every way, as good a pavement as another asphalt which has proved a success.

"7th Answer. The requirements of an asphalt for paving purposes are of such a peculiar nature that it would be impossible for a chemist who had not made the subject a special study to state with certainty, from the results of analysis, whether or not a given sample would make as good a pavement as an asphalt which has proved a success.

"8th Answer. The real and final test of the quality of an asphalt for paving purposes is actual trial for a proper length of time. Proper chemical and physical tests of a new variety of asphalt may strongly indicate its probable value as a paving material, but these tests, though of great assistance in forming an opinion, really only show the advisability of submitting the asphalt to the final and infallible test of actual trial.

"9th Answer. A test of one or two years under any condition demonstrates only that that particular asphalt pavement is good for that length of time under those conditions, and does not demonstrate how much longer it will last under the same conditions or whether it will last as long under other or more unfavorable conditions. Two asphalt pavements might endure equally well for a given short time, and yet show decided difference under a long trial.

"Having thus briefly answered the questions asked it may, perhaps, be well to give some explanation of the subject, in order to indicate the reasons for the opinions expressed. First of all, it may be stated that asphalt is not a chemical compound or mineral of fixed and invariable composition. According to Dana it is a mixture of hydrocarbons, and the asphalts of different localities have various compositions. Mineralogically, bitumen is simply another name for asphalt or asphaltum. In paving parlance, however, bitumen has come to mean only the pure portion, so to speak, of the asphalt, the latter term being applied to the entire mixture of earthy and other impurities with the true bitumen. This view of bitumen having evidently been taken in the questions asked, it was similarly considered in the replies. It is to be understood, then, that asphalt is an impure bitumen, and that bitumen is the pure article considered by Dana in his Mineralogy. But, as before stated, bitumen has no fixed composition or combination of qualities. Its nature and physical properties are as various as the localities where it is found. It can be no more strictly defined than coal. It is simply a mixture of various hydrocarbons, and may be either a solid or a liquid. Two bitumens of precisely similar percentage composition may have widely different properties, so that while one would furnish a most excellent paving material the other would be practically worthless. Such instances of substances of entirely dissimilar nature having the same percentage composition abound in chemistry. Charcoal, the diamond, and plumbago, or black lead, may be mentioned as a familiar example. Light naphtha or gasoline and solid paraffine is another. It takes more than an ordinary chemical analysis to distinguish between such substances. Evidently, then, the mere percentage of bitumen in an asphalt would not determine its value for paving purposes, for this bitumen might have a consistency varying anywhere from a non-cohesive liquid to a brittle worthless solid. By the action of the elements all asphalts undergo change. This change is due to oxidation, volatilization and other molecular disruption, and tends to produce greater solidification or apparent drying, and the asphalt may pass through all the stages of brittleness to final crumbling or disintegration. In all these stages the substance is still asphalt, although at many points it is evidently worthless as a paving material. While these changes are slow in nature, some of them may be greatly hastened by the application of heat, as in incautious or unskilful refining so as to greatly injure an originally good asphalt. It is evident, also, that an asphalt may be so far gone in the process of natural decay that, while it may serve to make what appears to be an excellent pavement, the life of such a pavement must be comparatively short.

"Having thus shown how much depends upon the quality or nature of the bitumen in an asphalt rather than upon its mere percentage, it becomes important to know to what extent the chemist can distinguish this valuable quality, and so prevent disastrous mistakes in pavement work. It may be answered that a chemist who has made a special study of the subject can, by proper chemical analysis, aided by certain physical tests, point out what is probably good or worth trying in the case of new varieties, but it is impossible for him to state for a certainty that a particular new variety will be fully equal in every essential respect to some standard asphalt that has proved a success. Having learned by experience the chemical and physical differences between good and bad samples of any particular asphalt, the chemist may thereafter afford valuable assistance in the use of that asphalt.

"In view of the foregoing facts it would seem that the extensive use, for paving purposes, of any variety of asphalt that has not previously been proven a success by the test of actual trial for a sufficient length of time, under sufficiently adverse conditions, is in the nature of a rather hazardous experiment.

"Trusting that the above answers and explanations will prove clear and satisfactory, we will add that they are given without prejudice and according to our best knowledge of the subject,

"Yours respectfully,
(Signed) "CHEMIST."

Action of Water on Asphalt in the Laboratory.—It has frequently been claimed that there is a preference for one asphalt over another based upon the manner in which it behaves towards water when it is placed in contact with it in the laboratory. From data which will be given elsewhere[1] it appears that this method of examining them is not one the results of which are confirmed by practice. All asphalts are attacked by water under certain environments and some more than others under certain laboratory conditions. In practice, however, the results obtained in the laboratory are not confirmed if the asphalts are employed so as to bring out their most desirable qualities.

Bearing in mind all these considerations it is not difficult to form a decided opinion as to the desirability of any native bitumen for the uses to which it is put in the paving industry.

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[1] See page 460.

CONCLUSIONS.

From the preceding data and discussion it is very evident that while many native bitumens may be denominated asphalt, from an industrial point of view, they possess no great uniformity in their physical and chemical properties and that some of them are far preferable to others for paving purposes. Some of them are extremely stable bitumens while others are more or less changeable on the application of heat. Some of them are hard, others are comparatively soft. Some evolve gas on heating, showing that they are unstable. Some lose on heating a considerable amount of light hydrocarbons, petrolenes, with corresponding hardening in the consistency of the material. Some asphalts are obtainable in unlimited amounts and of great uniformity in composition. Others, while obtainable in large amounts, are very variable in their consistency, the character of no two shipments corresponding in this respect. Some asphalts, such as those which are obtained by collecting the exudation from maltha springs, are not only very variable in their character but, being still in a state of transformation from maltha to asphalt and, therefore, not in equilibrium, are unsatisfactory materials for use in the paving industry or require such great skill or judgment in their treatment as to make it difficult to construct good work with them.

From the results of the author's experience with all the bitumens which have been used in the construction of asphalt pavements during the last eighteen years the conviction has been forced upon him that none of them, with the exception of gilsonite, which has recently proved itself under service tests to be a very desirable material, is as uniformly satisfactory as that obtained from the Trinidad pitch lake, and for the following reasons:

1. The available supply is unlimited.

2. The supply is of great uniformity, as appears from data given in the preceding pages.

3. Asphalt cements prepared from Trinidad lake asphalt and stable flux are less liable to change in consistency when maintained in a melted condition at high temperatures for any considerable length of time or on being tossed about in a mixer with

excessively hot sand, something that unfortunately happens too frequently, than one derived from any other form of bitumen.

4. It is less susceptible to changes in consistency at extremes of temperature than any other native bitumen which is now used extensively in the construction of asphalt pavement.

5. The relation of malthenes to asphaltenes is such that the proportion of flux which is necessary to produce an asphalt cement of normal consistency is not excessive.

6. The mineral matter which it contains is of a nature most suitable to play the rôle of a filler and it is mixed by nature with the bitumen in a way that it is impossible to imitate by adding finely powdered mineral matter to a purer form of bitumen.

Trinidad mixtures, when the mineral aggregate is properly graded and regulated, are not attacked by water to any greater extent on the street than mixtures made with other asphalts. In fact surface mixtures of Trinidad asphalt resist impact more satisfactorily after three months exposure to running water than those made with Bermudez asphalt, as shown by the following figures:

IMPACT TESTS OF ASPHALT SURFACE MIXTURES.

	New York.	
	Trinidad.	Bermudez.
Density	2.24	2.24
Number of blows:		
Original material	21–20	16–14
After 3 months' exposure to running water	20	13
Water absorbed:		
Pounds per square yard	.129	.157

Bermudez asphalt possesses the disadvantage that it is far from uniform in character, that the bitumens of which it consists are susceptible to volatilization at high temperature with a resulting hardening of the material, as for example when it is mixed with very hot sand; that is to say, it does not form an asphalt cement which can be maintained at high temperatures or mixed with sand at high temperatures satisfactorily and for this reason cannot be used in cold weather, and because it is deficient, in comparison with Trinidad asphalt, in mineral matter forming a natural filler. As has already been shown, surface mixtures made with Bermudez asphalt are more deteriorated by the continued action of water, as far as their resistance to impact is concerned, than those made with Trinidad asphalt.

Maracaibo asphalt is not a normal asphaltic bitumen and possesses characteristics which throw a doubt upon its suitability for the preparation of a paving cement, which can only be removed by a study of its behavior after a long period of years in actual practice.

Mexican asphalts are far from uniform and possess the same disadvantages that pertain to Bermudez asphalt. Their use would involve greater care and skill than any of the materials that have been mentioned.

Cuban asphalts are very hard materials, approaching grahamite in composition, and must be fluxed with very large proportions of asphaltic oil. Their value as paving materials has never been satisfactorily demonstrated.

The solid residuals from asphaltic or semi-asphaltic oils are far from uniform and are generally somewhat damaged or cracked in the course of their preparation. The closest scrutiny of these materials in the laboratory and the greatest skill in handling them is necessary to enable them to be used satisfactorily in the construction of asphalt surface mixture.

Gilsonite has now been submitted to sufficient service test to show that as a paving cement it is equal in character to any asphalt in use for this purpose. A pavement was laid with it in 1903 on Missouri Avenue, Main to Delaware, Kansas City, Mo., under the author's direction, and it has proved entirely satisfactory. Since that time it has been used equally successfully to a large extent in other cities. Gilsonite may therefore be added to the list of those bitumens which are entirely suitable for paving purposes, if properly handled. This, of course, means that the material shall be fluxed with an asphaltic oil, as a paraffine flux is entirely incompatible with the material.

The preceding criticisms of the various asphalts which have been used in the construction of asphalt pavements lead at once to the conclusion that Trinidad lake asphalt or gilsonite is the best for this purpose. In the author's mind there is no reasonable doubt that this conclusion is correct. It is not intended, however, to assert that satisfactory pavements cannot be constructed from the other asphalts, especially where the latter are not subjected to trying environment or a heavy traffic and where considerable skill is exercised in their use. It is asserted, however, that with Trinidad asphalt there is greater probability that a pavement constructed with it will be satisfactory, taking into account the fact that a greater or less lack of care is inevitable in preparing an asphalt surface mixture from any bitumen. Trinidad asphalt will stand more abuse than any other material with which we are acquainted, and on this account is to be strongly recommended, as well as because less skill is required in handling it.

SUMMARY.

In this Chapter there is outlined the characteristics which make any solid native bitumen available and desirable for paving purposes. These characteristics are as follows:

1. The quantity available.
2. Its uniformity in character.
3. Its stability in a melted condition at high temperatures.
4. Its stability in consistency at the extremes of temperature which it meets in an asphalt pavement.
5. The proportion of malthenes to asphaltenes which it contains.
6. The proportion of flux which is required to make an asphalt cement.
7. Mineral matter present and its character.

It appears that Trinidad lake asphalt and gilsonite fulfil more of the necessary requirements than any other commercial supplies of native bitumen for the purpose of constructing asphalt pavements.

It also appears that properly constructed surface mixtures made with Trinidad lake asphalt are no more acted upon by water than those made with other asphalts, and that the charge that they are acted upon to a greater extent is dependent purely upon laboratory experiments without regard to making the conditions under which they are carried on conform to those which are met with on the street.

PART IV.

TECHNOLOGY OF THE PAVING INDUSTRY.

CHAPTER XV.

REFINING OF SOLID BITUMENS.

Asphalts which contain water as they occur in nature must be freed from it before they are in a condition to be used in the paving industry. The process of bringing this about is called refining. It really is nothing more than some method of drying the asphalt, in some cases removing the more volatile hydrocarbons, the loss of which, at a later period, from the asphalt cement would make the latter of unstable consistency, and skimming off any vegetable matter which may rise to the surface of the melted material. The process was originally called refining because, before the value of the fine mineral matter was understood, much of this was separated out by subsidence from the melted bitumen and the resulting asphalt was actually refined, having been made purer or richer in bitumen. To-day the refining goes no further than the removal of such organic contamination as may rise to the surface of the melted asphalt after the water has been evaporated, and the volatile hydrocarbons have gone off with the steam, and the thorough mixing of the residual mass to a condition of uniformity in composition, the mineral matter being maintained for this purpose in suspension, in the meanwhile, by agitation of the melted material in any convenient way.

The drying process is conducted in two different ways. The material is filled into an iron tank or melting-kettle which is heated by a free fire, the bottom of the kettle being protected by an arch of brick; or a large rectangular tank is used, the interior of which is filled with gangs of pipe through which steam is conducted at such a pressure as to raise the asphalt to the same temperature that is produced over the free flame but without any danger of exceeding the highest temperature which the pressure of the steam will yield. Fig. 18.[1] In either case, since convection in such a viscous mass is very slow, agitation is carried on with either a current of air or steam, in the latter case the current not being admitted until the asphalt is melted and exceeds the boiling-point of water, this being necessary to prevent condensation and subsequent foaming. The temperature must, of course, be raised slowly at first to avoid foaming when the bitumen melts easily and the asphalt contains much water. When the temperature has been raised to a point where the material is thoroughly melted and steam is no longer given off the process is finished and the refined asphalt is ready to be drawn off. The details of this process are ones purely of economy, the object being to dry and get the asphalt into packages suitable for handling. Where the material is to be made into cement and used on the spot, the latter is unnecessary. The packages are usually old hydraulic cement barrels which before use are clayed on the inside by being revolved in a bath of clay and water. The claying is done to make it possible to strip the staves from the asphalt more easily when preparing it at its destination to be made into cement and to do this with the loss of the least possible amount of asphalt adherent to the staves.

In the fire refining method four or five days are required to complete the operation. In refining solid bitumens in this way danger is always incurred of overheating them, with the formation of coke and the cracking of the hydrocarbons. There is a certain formation of coke in all cases where a direct flame is in use and that some asphalts are injured during the process is shown by the fact that the resulting bitumen is not entirely soluble in cold carbon tetrachloride. To avoid such difficulties a very thorough mechanical or other form of agitation is absolutely essential.

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[1] Page 405.

By the steam process the refining is completed in 24 hours or less without any danger of injury to the bitumen from overheating. The agitation in this process is generally by means of dry steam. The use of steam results in the volatilization of a rather larger amount of lighter oils than occurs with air agitation and it may be possible, for this reason, that it could be replaced by air beneficially, although hot air has a decidedly strong effect upon native bitumens as has been shown in connection with the condensed oils.[1]

From ten to twenty-five or more tons are refined at once, the larger amounts by the steam process, and the temperature reached is about 325° F.

Almost all asphalts require refining but some other native bitumens which can be, and are, used to a small extent in the paving industry, are anhydrous and need no drying. Gilsonite and grahamite need no refining, being practically dry and pure bitumens.

The Preparation of the Asphalt Cement.—Whatever solid bitumen and flux are selected for the purpose, their careful combination is necessary for the preparation of a satisfactory asphalt cement. The carefully weighed asphalt is melted and raised to a temperature of about 300° or 325° F., or if the material is taken on the immediate completion of refining, as happens where a refinery and paving plant are associated, it is carefully gauged. The flux, having preferably been heated with steam coils in the receptacle containing it to 150° to 200° F., is then slowly run into the melting-tank holding the asphalt, agitation with air or steam having been established, the air or steam being admitted through lines of pipe, perforated with frequent openings and which lie along the bottom of the tank. A satisfactory and sufficient agitation is most essential and steam has been found more suitable than air where its use is possible. It should, of course, be high pressure steam and it should not be admitted to the melted asphalt until the latter is at such a temperature as to prevent condensation. Every provision should also be made that the steam be quite dry by blowing all condensed water out of the pipes carrying it. Neglect to do this will, otherwise, cause dangerous foaming. A check-valve should also be provided at a point above the surface of the melted asphalt to provide for the admission of air when the steam is shut off and prevent condensation and the production of a vacuum which will draw the melted asphalt cement back into the agitation pipes and clog them. Air agitation is simple and fairly satisfactory but the effect of blowing hydrocarbon oils with air results in hardening them and changing their consistency in a marked degree and on that account is undesirable.

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[1] See page 273.

The agitation, of whatever kind, should be kept up until the solid bitumen and liquid flux are thoroughly mixed and in homogeneous solution. The length of time required will depend on the force of the current of steam or air and the character and temperature of the melted materials. Under the most favorable circumstances three hours are requisite and with inferior agitation eight or more may be necessary.

To the eye of the experienced yard foreman the point at which the combination is complete and the mixture homogeneous will be evident, but the material can be tested by pouring some of it into a pail of cold water and examining it on cooling Any oiliness is a sign that more agitation is necessary.

The asphalt cement having been found to be homogeneous the next step is the determination of the fact that the consistency is that which is desired. This can be arrived at in various ways of greater or less refinement. The ordinary, and always the preliminary test, is that of chewing a small piece of the cement cooled by pouring it into cold water. On putting the cement in the mouth and working it between the teeth it rapidly assumes the temperature of the mouth which is a very uniform one, that of the normal temperature of the body, 98.4° F. The amount of work that is done by the jaws upon the cement will readily show whether it is harder or softer than what experience has taught to be a proper consistency and it is not difficult for one who makes this test daily to decide whether the asphalt in question is within four or five points of the consistency desired and registered by the more accurate penetration machine. In experienced hands it is questionable whether a more accurate test is absolutely necessary, except as a matter of record.

A more refined test which is available for use by the yard foreman at the plant is that known as a flow test which permits, according to a method described in Chapter XXVIII of comparing the relative flow, at temperatures above the softening point of the cement of the material to be tested with that of a standard of the desired consistency prepared in the laboratory.

Where a definite determination is required for purposes of record one of the several penetration machines may be used, but these require careful manipulation and their use sometimes necessitates greater refinement than a yard foreman is capable of.

Under any circumstance it is absolutely necessary that the consistency of the asphalt cement shall be so regulated that it will be entirely uniform for any one piece of work. What this consistency shall be will depend upon the character of the work which is being done and upon its environment, both as to traffic and climate. The variations in this respect will be discussed later.

If the cement is to be held in a melted condition for any length of time agitation must be maintained, especially if it contains mineral matter. The purer native bitumens and residues from asphaltic petroleums require very little beyond that necessary to prevent any one portion remaining for any great length of time in contact with the source of heat, whether the walls of a tank heated by direct flame or the steam coils. All cements can be allowed to become solid and cold if they are thoroughly agitated again on remelting. On the other hand too powerful agitation is injurious as it volatilizes the lighter portions of the cement and hardens it. Continued agitation with air has a marked effect upon the character of all oils by the extraction of hydrogen and condensation of the hydrocarbons to a short rubbery solid such as the blown petroleum now to be found on the market as an article of commerce, and which has been already described. The result of continued air agitation, therefore is to harden an asphalt in two ways, by the volatilization of the lighter oils and also by increasing their density by condensation of two molecules into one. Steam hardens a cement only by the volatilization of the lighter constituents. Steam is, therefore, probably preferable for the agitation of a finished asphalt cement, although air may be more desirable as a means of agitation during refining.

The actual changes which take place with different fluxes and different asphalts will be shown further on.

Character of Various Asphalt Cements.—The character of an asphalt cement depends upon that of the solid bitumen and of the flux from which it is prepared.

Asphalt cements may be divided into several classes.

1. Those composed of the standard solid native bitumens, such as Trinidad and Bermudez asphalts, and paraffine petroleum residuum.

2. Those composed of the same asphalts and fluxes or residuums from asphaltic petroleums.

3. Those made from the same asphalts and fluxes which are mixtures of asphaltic and paraffine oils.

4. Those made from other solid native bitumens and asphaltic fluxes.

5. Those composed of solid residual bitumens from asphaltic petroleum brought to a proper consistency with residuum of the same origin.

6. Any of the first four classes with the addition of small amounts of the condensed or blown oil, or other forms of bitumen not constituting one of the main constituents of the cement.

Asphalt Cements Composed of Trinidad or Bermudez and Similar Asphalts and Paraffine Petroleum Residuum.—Some years ago there was a popular prejudice against the use of paraffine petroleum residuum as a fluxing agent for asphalt. This was not founded on the results of any careful investigation or tangible evidence. It arose at first from a desire to find some excuse for the poor wearing quality of some carelessly constructed asphalt pavements and from the fact that the earlier surfaces were readily attacked by water where subjected to its action for any length of time. It was claimed:

That a part of the residuum of paraffine petroleum is soluble in water and that by the continued action of the latter on the oil in the asphalt cement, the cement is deteriorated.

That on standing in a melted condition the petroleum oil rises to the top of the cement and can be "skimmed off like cream."

That the bitumen of Trinidad and other asphalts are not completely soluble in paraffine residuum but are only mechanically mixed.

The fallacies in two of these claims are readily shown.

That the first is false is shown by the fact that distilled water which has been allowed to stand in a glass-stoppered bottle in contact with standard paraffine residuum for four years is as bright and clean as when first put there and contains nothing in solution.[1]

The second is equally wrong since a tank of asphalt cement maintained one week at a temperature of 300° F., without agitation, on cooling, was not to the slightest degree oily or greasy on the surface, which would be the case if any oil had separated like cream.

The proposition that the bitumen of Trinidad and other asphalts is not completely soluble in standard paraffine petroleum residuum can be equally well disproved and it can be shown that asphaltic bitumens are as soluble in paraffine residuum as in the asphaltic oils of California. The results of some experiments in this direction by the author were presented in articles in "Municipal Engineering" for June, July and August, 1897, and for June, 1899. The experiments and conclusions arrived at and presented in the latter article were, in the main, as follows:

"Three asphalt cements, prepared with great care and uniformity, as appears from the results of duplicate analyses of the original material, were placed several inches deep in glass tubes 8 inches long and $\frac{3}{4}$ of an inch in diameter and maintained at a temperature of 325° F. for three days, being centrifugaled at that temperature several times to assist any separation that might take

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[1] Messrs. Whipple and Jackson in a paper read before the Brooklyn Engineers Club and published in the Engineering News for March 22, 1900, have shown that petroleum residuum is affected less by water than any bituminous substance that they examined.

"RESULTS OF CENTRIFUGAL ACTION ON VARIOUS ASPHALT CEMENTS.

"100 lbs. Trinidad + 20 lbs. of paraffine residuum.

	Original Cement. Duplicates.		Top 45 Per Cent. Duplicates.		Bottom 45 Per Cent. Duplicates.		Sediment, 10 Per Cent
"Bitumen soluble in chloroform	....		....		....		27.6
Bitumen soluble in CS_2	63.4	63.5	69.9	70.1	68.5	68.7	26.8
Bitumen soluble in 88° naphtha	48.6	48.7	53.4	53.4	52.7	52.9	22.3
Per cent of total bitumen thus soluble	76.6	76.6	76.3	76.2	76.9	77.0	83.2
Per cent of total bitumen insoluble	23.4	23.4	23.7	23.8	23.1	23.0	16.8
Mineral matter	30.3		23.9		25.1		65.5
Difference	6.3		6.2		6.4		5.4
Penetration	55°		49°		51°		0

"100 lbs. Trinidad + 27 lbs. California 'G' grade flux.

"Bitumen soluble in chloroform	....		....		....		27.3
Bitumen soluble in CS_2	64.7	64.8	71.6	71.9	70.2	70.4	26.8
Bitumen soluble in 88° naphtha	51.1	51.3	55.7	56.0	55.1	55.4	22.5
Per cent of total bitumen thus soluble	79.0	79.2	77.8	77.9	78.5	78.7	84.0
Per cent of total bitumen insoluble	21.0	20.8	22.2	22.1	21.5	21.3	16.0
Mineral matter	28.9		22.9		23.0		65.8
Difference	6.4		5.5		6.8		7.4
Penetration	46°		47°		50°		0

"100 lbs. Bermudez + 18 lbs. of paraffine residuum.

"Bitumen soluble in chloroform	....		....		....		67.5
Bitumen soluble in CS_2	92.6	92.8	96.2	96.4	95.2	95.4	66.8
Bitumen soluble in 88° naphtha	73.1	73.2	74.5	74.7	73.6	73.8	53.9
Per cent of bitumen thus soluble	78.9	78.9	77.4	77.5	77.3	77.4	80 7
Per cent of total bitumen insoluble	21.1	21.1	22.6	22.5	22.7	22.6	19.3
Mineral matter	3.2	3.3	1.9		2.2		15.0
Difference	4.2	3.9	1.9		2.6		8.2
Penetration at 78° F	60°		56°		55°		0

place. On cooling the asphalt was divided into three parts; an upper, 45 per cent; a lower, 45 per cent; and the bottom, 10 per cent, of sediment. The consistency and composition of these portions were then determined by the most careful methods, extracting with naphtha and carbon disulphide, filtering on a Gooch crucible and burning the bitumen solution for any inorganic correction. The results were obtained in duplicate, except in the case of the sediment. Their agreement is confirmatory of their accuracy. See results tabulated on page 298.

"These results show that there is no difference in the character of the bitumen in the cement made from Trinidad asphalt and residuum in the two portions of cement above the residue, after heating and subsidation, from that of the original material. With California oil and Bermudez asphalt there is a slight loss of oil in the upper portions and consequent small reduction in the percentage of naphtha soluble bitumen. In the sediments the proportion of naphtha soluble to total bitumen has increased in all three cements. The fact that something in the cement more soluble in naphtha and heavier than the ordinary constituents has been thrown down, is peculiar."

What this is it is impossible to say at present, but it appears from a paper by R. P. Van Calcar, which has recently appeared in the *Recueil des Travaux Chimiques des Pays-Bas*,[1] that where solutions of various salts in water were subjected to a centrifugal force 400 times that of gravity they became more concentrated at the periphery after a few hours, contrary to the preconceived ideas that the molecules in a true solution were unaffected by gravity, and hence were in a different state from those in colloidal solutions. As a consequence of Van Calcar's conclusions the results obtained with the asphalt cement are not unexpected.

"As a whole the results seem to the writer to refute the statements which have been made in regard to residuum and to show that 90 per cent of the asphalt cement made of Trinidad lake asphalt and residuum was unchanged to any perceptible degree after the severe treatment it had been subjected to by standing and centrifugaling at a high temperature, while any changes that took place in the sediment were found as well in cements made with the California residuum or so-called asphaltic flux."

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[1] Science, 1904, August 19, 20, 250.

As a matter of fact there is no evidence to show that there is any essential difference between the California fluxes and paraffine residuums in their power of dissolving the bitumen of Trinidad and Bermudez asphalts, or that the latter is not a satisfactory flux, on this account, for making asphalt cements with these asphalts. The successful use of it in many pavements laid twenty years ago, which are now in perfect repair, is the best evidence that it is satisfactory.

Amount of Residuum Necessary in Making An Asphalt Cement.—The amount of paraffine residuum oil which it is necessary to use per 100 pounds of Trinidad or Bermudez asphalt to make a cement of satisfactory consistency depends on the character of this flux. It may be very variable, but with a standard material should not vary more than 4 pounds per hundred of the asphalt. With some less carefully prepared residuums the difference may be 6 pounds. For example the oil in use by one company in 1899 and by another in 1898 had the following characteristics:

Residuum	Light	Heavy
Specific gravity, 78° F./78° F., orig. mat., dry	.9197	.9331
Beaumé	22.7°	20.5°
Flashes, ° F.	330° F.	442° F.
Loss, 400° F., 7 hours	17.3	3.8%
Pounds per 100 of asphalt to make asphalt cement of 60° penetration:		
Trinidad lake	16	22
Bermudez 1899	14	23

Much less of the lighter oil would produce the same softening effect as the larger quantity of the heavier residuum. It becomes a question then to determine as far as possible which is the most desirable cement and the only evidence that is available are the results of an examination of the two cements as to the change in their consistency at such extremes of temperature as are common in pavements and as to their change in penetration on being maintained in a melted condition for some time. Experiments in these directions furnish the following information:

COMPARISON OF CONSISTENCY OF ASPHALT CEMENTS AT DIFFERENT TEMPERATURES WHEN MADE WITH DIFFERENT FLUXES.

Asphalt.	Residuum.	Pounds per 100 of Asphalt.	Penetration at		
			45° F.	78° F.	100° F.
Bermudez.......	Light	14	30°	60°	105°
"	Heavy	23	32	60	125
Trinidad.......	Light	16	29	65	120
"	Heavy	22	29	63	115

PENETRATION AND LOSS AFTER HEATING TO 300° FAHR.

		Penetration at 78° F.			Loss.			Total.
		Original.	After Heating 4 Hours	After Heating 6 Hours	1st 2 Hours	2d 2 Hours	3d 2 Hours	
Bermudez...	Light	60°	36°	30°	1.36%	.79%	.71%	2.86%
" ...	Heavy	60	50	45	.50	.40	.30	1.20
Trinidad....	Light	65	35	30	1.56	.75	.58	2.89
"	Heavy	63	40	38	.98	.34	.33	1.65

At temperatures between 78° and 45° F. there is no great difference in the penetration of cements made with heavy and light residuum. At higher temperatures there is a considerable but not constant difference. In the case of Bermudez cements, that made with the heavy oil is softer at 100° because of the greater softening effect of the larger amount of flux, 23 pounds, as compared to 14 of the lighter oil, while with the harder Trinidad the reverse is the case. As will be seen later, a flux which is so dense that an excess of it is required to produce a cement of normal consistency at ordinary temperatures may make a cement more susceptible to high temperatures than a lighter or less dense one.

As to the permanency of the two classes of cement, however, the figures show that on maintaining it in a melted condition, and of course on mixing with hot sand, there is a much larger loss of oil and a greater hardening of the cement fluxed with light than with heavy residuum. For this reason alone cements made with the heavier oil seem, up to a certain point, decidedly preferable to those made with the lighter forms in use. Determinations of the consistency of the bitumen in old surfaces laid with cements made with light residuum as compared with others holding heavy oil confirm this. Surfaces in Omaha were laid in 1890 in part with a light, so-called summer oil, and in part with a heavy one. The consistency of the bitumen in these different surfaces when laid and again on extraction was as follows:

Flux in Cement.	Original Pen.	Pen. 1899.	Loss.
Light	67°	35°	32°
Heavy	50°	30°	20°

It seems that the cement made with the very light oil has hardened, either in the mixer or by age, to a much greater extent than the other.

Many good pavements have been made with the lighter fluxes, however, and it would be unfair to condemn them entirely, or to say that they are necessarily the cause of defects in asphalt surfaces, but it seems plain that the heavier oil is in general the more satisfactory although more of it must be used.

In the light of the previous results no valid objection can be raised and maintained against the use of a suitable paraffine petroleum residue as a flux for Trinided lake and Bermudez bitumens in the preparation of an asphalt cement, and this is not surprising when it is considered that many million yards of satisfactory pavement have been laid with such a cement.

Paraffine residuums are to be found on the market, and this was the case very frequently in the early days of the industry, which are, owing to the manner in which they have been prepared, quite unsuitable for use, but this has no bearing on the question of the availability of standard material.

For fluxing Trinidad land asphalt and others of a hard nature paraffine residuum is not suitable because of the deficiency of lighter malthenes in these asphalts, the lack of which is not made up by the hydrocarbons of such a residuum.

Asphalt Cements Composed of Trinidad or Bermudez and Similar Asphalts and Flux or Residuum from Asphaltic Petroleums.— Trinidad, Bermudez, and other similar asphalts can be satisfactorily fluxed with the asphaltic residuums which are prepared in the East from Texas oil and are now on the market. The character of this residuum has already been described. It is a most desirable material and can be used in about the same proportions and in exactly the same way as the paraffine petroleum residuum. It should not, however, be so dense as to necessitate the use of excessive amounts of it, since under these conditions, as was shown to be the case with paraffine residuum, the resulting asphalt cement will be too susceptible to high temperatures. The density should be such that not more than 22 pounds of oil per 100 of refined Trinidad or of Bermudez asphalt shall be required to produce a cement of 65° penetration on the Bowen machine. Such an oil will have a density of .95. The heavier residuum of a density of .97, also found on the market, is not satisfactory, although this flux has its use with certain other native bitumens.

Comparing the general characteristics and stability of the two forms of residuum it has been found and confirmed by practical experience that there is probably a slight preference in favor of a not too dense asphaltic flux, but this difference is not sufficiently great to make it obligatory to use the latter except in work of the very highest character on streets which carry very heavy traffic and where it is certain that the character of the asphaltic will be as uniform and satisfactory as that of the paraffine flux, and unfortunately this is not always the case. The greatest care is necessary in its preparation, as any overheating or cracking in the latter will result in the presence of light oils which volatilize readily and cause a rapid change in the consistency of the cement, while maintaining it in a melted condition or during the time that the cement is being tossed about in the mixer in contact with hot sand during the preparation of surface mixture. It is possible, therefore, that in comparison with an asphaltic flux of inferior grade a paraffine residuum may be preferable.

Combinations of Trinidad, Bermudez, and similar asphalts with the heavy California flux known as No. 2 or G grade are not satisfactory, since the proportion of such a flux to the asphalt in order to produce a cement of proper consistency is so large, being in the neighborhood of 60 pounds of flux to 100 of Trinidad asphalt, that the resulting material is excessively susceptible to high temperatures. Such combinations are, therefore, rarely used. Where the solid asphalt is one that has been much hardened by age or exposure, as in the case of that from La Patera in California, a supply of which is no longer on the market, the mine being exhausted, the use of a heavy California flux or a very dense Texas residuum is imperative, at least as a preliminary fluxing material, to supply the lack of denser malthenes in the asphalt. If a certain amount of this flux is used, however, the remainder can be of a lighter form, and probably preferably so. Asphalts of this description are not at present of commercial interest, with the exception, perhaps, of that obtained in Cuba from the Bejucal mine.

Asphalt cements have sometimes been made from the solid native bitumens, including the asphalts, and the natural malthas. Pavements constructed with asphalt cements made in this way have proved, however, to be unsatisfactory. Some experiments were conducted some years ago by the writer to determine why such asphalt cements were not satisfactory.

In the laboratory it was found that the solubility of the bitumens of Trinidad and Bermudez asphalts was as great in the ordinary malthas as in the residuums from paraffine and asphaltic petroleums. There was no preference in this respect. When, however, the permanence of consistency of malthas when exposed to heat was compared with that of residuums, there was found originally to be a great deficiency in that of the malthas.

Residuum such as is at present in use has already been shown to volatilize but a small amount when heated in an open dish in a bath kept at 400° F. for 7 hours, and to remain of the same, or very nearly the same, consistency after as it was before heating. The desirable features of a carefully prepared residuum as a softening agent are not lost on continued heating, nor is there sufficient oil volatilized at the high temperatures at which asphalt cement is maintained in a melted condition, with agitation for considerable periods of time in large masses, to change the consistency to any marked degree. As an example, a Trinidad lake asphalt cement made on February 29, 1896, by mixing 100,000 pounds of refined asphalt with 20,000 pounds of residuum had a penetration of 55°. It was held over a very low fire in a melted condition for 48 hours and then had changed in consistency so little as to penetrate 49°. After 73 hours melting the penetration was 46°. This is an extremely small change for such a considerable length of time.

Asphalt cements made with the native malthas behave quite differently. On heating for any considerable time they are converted into hard and glassy pitches by volatilization of oil, and, perhaps, by condensation of its hydrocarbon constituents. Such material is unstable and cannot form a cement which can be maintained at a uniform consistency.

On Saturday, February 29, 1896, in the early morning, 500 pounds of Bakersfield maltha was added to 2000 pounds of refined Trinidad asphalt, or at the rate of 25 pounds to the 100. After agitation the resulting asphalt cement penetrated 55°. It was allowed to stand with a low fire until the following Monday morning, March 2. The penetration had then fallen to 25°. On standing another 24 hours the penetration was found to be 22°. 270 pounds of additional maltha was then added, corresponding to 13.5 pounds per 100, which, after agitation, raised the penetration to 54°. After 4 hours of heating and agitation a sample was taken and found to penetrate but 35°.

It appears from this experiment that the light native California malthas are not suitable for the preparation of an unchangeable cement. Why this is so can be seen in the results of an examination of the maltha in the laboratory. While it is thick enough to require 5 pounds more of it to every 100 pounds of Trinidad refined asphalt to make a cement of the same consistency that is obtained with residuum, it loses on heating for 7 hours to 400° F. 20.3 per cent. This light oil is, of course, volatilized, in the same way, though more slowly, from the asphalt cement made with the maltha, and the loss causes the rapid fall in penetration and hardening of the cement.

An experiment with one of the asphaltic oils extracted from the abundant supply of asphaltic sandstone rock in Texas resulted similarly. The asphaltic oil, or maltha, as received was heated for some time at a low temperature to drive off any water and very volatile oil. A cement was then made of Trinidad asphalt and the maltha in the proportion of 100 to 80, which had a penetration of 65°. This cement was then maintained for 9 hours at a temperature of 325° F., when it was found to have hardened so much as to penetrate but 24°.

Of course satisfactory surface mixtures for paving cannot be made with such changeable material, and this is the reason that much of the earlier work done with California asphalt was a failure.

In fact, slight reflection shows that for a fluxing agent for softening hard asphalt a substance is needed which does not change its consistency after prolonged heating, and not another, though perhaps softer asphalt, which gradually becomes converted into a hard asphalt under the influence of heat.

Asphalt Cements Composed of other Solid Native Bitumens than Ordinary Asphalts and Asphaltic Fluxes.—Entirely satisfactory cements for use in the paving industry have been made from some of the other native bitumens, especially Gilsonite, by fluxing them with an asphaltic oil. For this purpose about equal parts of the Gilsonite and flux are necessary. The resulting cement contains bitumen in the form of the classes known as malthenes and asphaltenes in normal proportions, about the same as in Trinidad and Bermudez asphalt cements, as will appear from data on page 308. On this account, such cements may be regarded as entirely normal in character, and the fact that they contain a large proportion of flux is not open to comment, especially as the hard bitumen and the oils combine homogeneously and no free flux is found in the cement.

Asphalt Cements Composed of Solid Residual Bitumens from Asphaltic Petroleum Brought to a Proper Consistency with Residuum of the Same Origin.—From the asphaltic petroleums, such as those found in California and Texas, residual pitches or solid bitumens are prepared by distillation, and the characteristics of these solid bitumens have been already described. Asphalt cements can be prepared for paving purposes from these residual pitches by bringing them to a proper consistency with a residuum or flux made from the same petroleum. These cements have been used with some success and also with many resulting failures. They are very susceptible to temperature changes, which necessitates the use of a very carefully graded mineral matter with plenty of filler and the greatest skill in handling them in order that they may not harden while being mixed with hot sand or reach the street at such a degree of softness that they mark up very rapidly under hot summer suns.

Cements of this description have been used to a very considerable extent on the Pacific Coast, and they are quite suitable for the climate of Southern California. In Washington and Oregon some difficulties have been met with where they have been employed.

Asphalt Cements of Any of the Previous Classes to which Amendments of Residual Pitches or Blown Oils Have Been Added.—Excellent asphalt cements have been prepared for paving purposes to which additions, not exceeding 10 per cent in amount, of condensed or blown oils, such as Pittsburg flux, Ventura flux, or blown Beaumont oil have been made. While the materials constituting these additions are in themselves unsuitable for paving purposes, they seem in some instances to modify the properties of native bitumen in such a way as to improve them, although in a manner that cannot be described. Such cements are not to be objected to, since they have been shown by experience to give satisfactory results.

Characteristics of Asphalt Cement.—It is of interest to note the characteristics of asphalt cement prepared from various bitumens with various proportions of fluxes, especially as to the relative proportions of the malthenes and asphaltenes which they contain. Some data in regard to this are given in the following table:

Asphalt.	Flux.	Proportions.	Pen. Bowen.	Bitumen by CS_2.	Mineral Matter.	Difference.	Bit. Sol. in 88° Naphtha.	Per Cent Total.	Fixed Carbon.
Trin. Lake .	Texas asphaltic	100–19.0	40	64.2	31.0	4.8	46.7	72.7	8.3
		100–25.0	60	67.6	28.3	4.1	50.2	74.3	8.2
		100–33.3	80	70.0	25.9	4.1	52.2	74.6	7.6
Trin. Lake .	Paraffine	100–19.5	40	64.7	30.5	4.8	46.0	71.1	8.9
		100–23.5	60	66.1	29.2	4.7	47.2	72.6	8.8
		100–26.6	80	67.5	27.7	4.8	48.6	72.0	8.1
Trin. Land.	Paraffine	100–17.6	40	63.1	30.9	6.0	44.3	72.0	9.2
		100–25.0	60	64.3	29.6	6.1	47.3	73.5	9.8
		100–28.2	80	65.5	28.8	5.7	49.0	74.8	9.0
Berm. Lake.	Texas asphaltic	100– 5.3	40	94.8	2.4	2.8	69.0	72.8	13.0
		100–14.9	60	95.2	2.4	2.4	71.6	75.1	12.1
		100–22.0	80	95.0	2.1	2.9	72.2	76.0	11.6
Berm. Lake.	Paraffine	100– 5.3	40	94.2	2.2	3.6	68.0	72.2	12.7
		100–14.9	60	95.5	2.0	2.5	71.0	74.3	12.4
		100–22.0	80	95.4	2.2	2.4	71.3	74.7	12.2
Gilsonite . . .	Texas asphaltic	100–85.2	60	99.7	.2	.1	76.3	77.1	8.1
		100–96.1	80	99.8	.1	.1	76.8	77.6	7.7
D grade, Cal.	G grade	100–12.4	80	99.7	.2	.1	70.8	71.5	16.0
Texas residual pitch	Texas asphaltic	100–20.4	40	98.6	.2	1.2	70.5	71.5	19.1
		100–25.0	60	98.9	.2	.9	71.9	72.7	18.3
		100–33.3	80	98.8	.1	1.1	73.8	74.7	17.2
Cuban Bejucal	Texas asphaltic	100–49.0	40	68.3	26.1	5.6	48.8	71.4	11.9
		100–50.0	60	70.0	23.5	6.5	50.7	72.4	11.1
		100–55.0	80	76.0	18.1	5.9	56.0	73.7	11.0
Grahamite. .	Texas asphaltic	100–150.0	40	99.5	.1	.4	63.3	63.6	9.8
		100–203.0	60	99.5	.1	.4	70.4	70.7	8.4
		100–233.3	80	99.5	.1	.4	71.3	71.6	8.1

Physical Properties of Asphalt Cement.—The character of a sheet asphalt surface of ordinary type will depend very largely on the properties of the cementing material which binds the mineral aggregate together, even if the latter is of the most approved grading and consequent stability. When the latter is not carefully arranged the physical properties of the asphalt cement will have an even greater influence on the behavior of the asphalt surface, more particularly under great extremes of temperature. It is important, therefore, to examine the properties of asphalt cements prepared from different solid native bitumens and softened with various fluxes. The properties which are of the greatest importance have been generally accepted to be their greater or smaller susceptibility to changes in consistency at the extreme temperatures which they meet under different climatic conditions and to their variable ductility.

The fact that asphalt cements vary in consistency, with change of temperature, means that at certain temperatures they are very viscous liquids and at low temperatures slightly viscous solids, the transition from one state to another being very gradual, although under modern theories of physical chemistry substances which are not crystalline can hardly be regarded as being solids. The slow flow of crude Trinidad asphalt, where large heaps of it are stored, is a well-known occurrence and corresponds very closely to that of the glacial flow of ice. The flow of an asphalt cement containing a very considerable proportion of flux is, of course, much more rapid. Mr. A. W. Dow[1] has shown that when cubes of asphalt cement are placed over a hole in a board at temperatures of 26° F., 75° F. and 140° F., the movement of the material into the hole was visible in 1 hour at 140° F., in a longer time at 75° F., and in 1 week at the lowest temperature. The fact that an asphalt cement will flow at this low temperature is of great importance in connection with the behavior of asphalt surface on the street in the winter months. Unless there is some ductility to allow for the contraction in the mass of the mineral aggregate all asphalt surfaces would crack at such a season. That they do not do so in all cases is to be attributed to this and to the fact that a suitable asphalt cement possesses such a consistency and lack of susceptibility to change in this respect between the lowest and the highest temperature to which it is exposed as to prevent it. Cracking frequently does take place in asphalt pavements from the lack of such qualities in the asphalt cement of which they are composed or from the absence of a sufficient amount of it as will appear in the discussion in later pages on the defects in asphalt pavements,[1] but is oftener due to the hardness of a cement rather than to its lack of ductility as experiments have shown that some asphalt cements, if sufficiently soft, although very short, may be sufficiently ductile to meet the demands made upon them at low temperature.

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[1] Municipal Engineering, 1898, 15, 364.

Experiments have shown that the ductility of an asphalt cement is proportionate to the amount of flux which it contains rather than to the character of the same and as the result of a very extended investigation, the results of which are too lengthy and numerous to introduce here, it has been made evident that too much dependence cannot be placed upon this characteristic in forming an opinion as to the availability of an asphalt for paving purposes.

The susceptibility of asphalt cements to changes in consistency with change in the temperature of its environment can be shown in several ways, most conveniently by determining the consistency at different temperatures with one of the various penetration machines in use for this purpose, by the relative elongation of cylinders of different cements under tension at different temperatures or, in the case of high temperatures, by the length of flow of small cylinders of cement on a corrugated brass plate in the manner described in Chapter XXVIII. If asphalt cements are prepared from different asphalts and fluxes of such a consistency that they all have the same penetration at the normal temperature, 78° F., and are then again penetrated at extremely low and high temperatures the relative changes in the consistency can then be determined, as has been already shown.[2]

In the following table are presented the results of the determination of the consistency of the asphalt cement made from various asphalts with fluxes of different character at 41° F. and 100° F. all the cements having the same consistency at 78° F.

Although the results speak for themselves it may be well to

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[1] See page 480–2. [2] See page 301.

Asphalt.	Flux.	Parts Flux to 100 of Asphalt.	Pen. Bowen, 78° F.	Penetrometer.		
				41° F.[1]	78° F.[1]	100° F.[1]
Trinidad Lake	Heavy	25	65	3	41	97
" "	Extra Heavy ...	34	65	2	42	113
" "	Paraffine	22	65	5	32	91
Bermudez	Heavy	17.5	65	5	44	100
"	Extra Heavy ...	24	65	3	40	109
"	Paraffine	15	65	3	39	108
Durango	None...........	...	65	3	43	98
Gilsonite	Heavy	127	65	5	34	63
"	Extra Heavy ...	170	65	5	37	82
"	Paraffine	122	65	7	30	48
Grahamite	Extra Heavy ...	270	65	6	28	35
Cuban Bejucal.....	Heavy	51	65	5	22	37

[1] 41° F. = 200 grams, 5 seconds; 78° F. = 100 grams, 5 seconds; 100° F. = 50 grams, 5 seconds.

call attention to some of the facts that are brought out by them. Among the Trinidad cements that made with extra heavy oil, and consequently requiring the largest proportion of flux, is much more susceptible to high temperatures, having a penetration at 100° F. of 113°, while that made with the paraffine oil, of which only 22 pounds per 100 was employed, has a penetration of only 91°, while all the Trinidad cements had practically the same penetration at 41° F.

Asphalt cements made with gilsonite and grahamite are much less susceptible to changes in consistency at extreme temperatures. At 41° F. cements made from these materials, although having the same penetration as the Trinidad, Bermudez, and California cements at 78° F., are much less hard and in the same way are softer to a less degree at higher temperatures. This would show that such cements would be more satisfactory for use in the paving industry where extremes of temperature are to be met than those composed of true asphalts.

SUMMARY.

In the preceding chapter the technology of the paving industry has been discussed in detail from the refining of the native bitumen to the preparation of the asphalt cement, together with a study of the character of the various asphalt cements made from different solid bitumens and with different fluxes. This chapter in its detail will interest principally the asphalt expert, the engineer, and the specialist.

CHAPTER XVI.

SURFACE MIXTURES.

THE surface mixtures of the early days of the asphalt paving industry consisted, as they do to-day, of asphalt cement, ground limestone, and sand; but even in 1893 very little attempt was made to specify the character of these consituents or to determine what rôles they play in the finished pavement. The asphalt cement was at one time soft, at another hard, at one time too small in amount and again too large, but oftener too small; the ground limestone was expected in 1884 to be only so fine that 16 per cent should be an impalpable fine powder and all should pass a No. 26 mesh, hardly what would be considered a dust to-day, and at times it was held to be doubtful if there were any necessity for the use of dust at all. The sand was sometimes coarse and sometimes fine, depending on the most available local supplies, and only in the later years were two kinds mixed and that without much reasoning.

In 1884 it was specified that the sand in use in Washington should all pass a 20-mesh sieve and none of it an 80.[1]

Surfaces with coarse sand and much cement marked or pushed and then the bitumen was reduced; with fine sand and low bitumen they cracked and the other extreme was again sought. Everything was done by rule of thumb and without reason. To this state of affairs much, but not all, of the cracking, displacement, and defects in pavements laid in the early nineties was due. The average consistency of the cement was the same for years and was too hard in most cases because the defective mineral aggregate would not permit the use of a softer one. The limestone dust was most of it sand and in consequence the amount of filler in the mixture was very deficient. But, worst of all, the sand grading was arranged by chance. Specimens of old surfaces were collected in 1894 and studied by the author at the request of the President of the Barber Asphalt Paving Company as being representative of the best work of the company up to that time, although they, on this account, hardly illustrate the average pavement of that day. They were analyzed in Washington and showed the following variations in their mineral aggregate, filler, and bitumen. Among these variations those in the sand grading are most striking.

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[1] Annual Report of the Operations of the Engineer Dept., District of Columbia, for the year ending June 30, 1884, 101.

AVERAGE COMPOSITION OF SURFACES FROM VARIOUS CITIES, LAID BEFORE 1894, ARRANGED ACCORDING TO THE PERCENTAGES OF 100- AND 80-MESH SAND THEY CONTAIN.

City.	Bitumen.	Mineral Aggregate Passing Mesh				Total.
		200.	100 and 80	50 and 40.	30,20, and 10.	
Washington	10.29	9.72	6.45	42.06	31.48	=100%
Louisville	8.91	14.50	9.06	38.30	29.23	=100%
Newark	8.81	8.38	9.48	41.26	32.07	=100%
St. Louis	9.61	10.87	12.12	60.10	7.30	=100%
Youngstown	9.06	10.93	12.77	49.06	18.18	=100%
New Orleans	9.87	11.27	15.34	52.59	10.93	=100%
New York	10.97	12.13	16.39	34.14	26.37	=100%
Scranton	10.64	12.15	22.01	37.58	17.62	=100%
Boston	11.75	14.46	35.32	26.19	12.28	=100%
Kansas City	9.85	13.10	25.92	31.31	19.82	=100%
Schenectady	10.32	11.91	29.19	39.38	9.20	=100%
Buffalo	9.65	11.32	30.53	44.68	3.82	=100%
Chicago	9.24	9.33	35.95	38.83	6.65	=100%
Omaha	9.44	12.80	41.98	24.93	10.85	=100%
Average	9.89	11.63	21.61	40.03	16.84	=100%
FOR COMPARISON.						
Standard mixture	10.5	13.0	26.0	34.5	16.0	=100%

These surfaces present every variety of grading in their composition and it is apparent that they could not all be satisfactory. Evidently no system was carried out in their production. The percentage of bitumen varies from 8.8 to 11.7, probably not from carelessness entirely but because the mineral aggregate would permit of the use of a large amount in certain cases and less in others. The amount of filler or 200-mesh dust is deficient in many cases, although in some it seems high enough, owing to the presence of sand of 200-mesh size which, as will appear, does not act as filler.

As will be shown later, the amount of 100- and 80-mesh material is deficient in the first seven cities and unbalanced in all. The grains of 10-, 20-, and 30-mesh sizes are present in far too large a degree in Washington, Louisvile, Newark, and New York, and are not well regulated in most of the cities. In fact the mineral aggregate in none of these towns was, at that time, well graded.

If the records of the Barber Asphalt Paving Company are studied for the 10 years before 1899, as summarized in the following tables, the reason for the varied composition of the preceding mixtures is explained. All sorts of sands were used, and probably, although there are no records, all kinds of filler. See results tabulated on pages 316, 317, 318, and 319.

If the average grading of the sand and of the mineral aggregates of these same cities be examined as far as the incomplete data will admit, the peculiarities of this part of the surface mixture are apparent. As fine sieves were not in use in the early days of the industry our knowledge of the grading of the finer part of the aggregate is limited, but in the sands of 1889 it is readily seen that in that used in Chicago there were not enough coarse particles, while the Newark and New York sands were only fit for concrete. Buffalo was deficient in 80- and 100-mesh particles, as were Kansas City, Louisville, and Washington. Other defects were apparent in this and the following years, to which it is unnecessary to call attention here, as the data are open to examination in the tables and the most striking points have been marked with asterisks. In 1893, for instance, all the sands were much too coarse except in Buffalo and Chicago. In 1894 they were much better. It is sufficient to say that up to 1894 no effort based on any well-defined reasons had been made to regulate the grading of the sand in surface mixtures or to accommodate the dust and asphalt cement to the demands of the latter, although it had been determined in 1892 that in the better class of pavements the sand was fine.

AVERAGE SANDS.

1889.

City.	Passing						Ret. 10
	70	50	40	30	20	10	
Boston							
Buffalo 1–B	8*	50	26	11	3*	1*	0
Chicago	29	49	16	5	1*	0*	0
Kansas City	20*	22	18	20	13†	7	1
Louisville	12*	43	22	12	5	3	1
Newark	6*	10	11	17	23	27	6
New Orleans							
New York	10	15	15	20	18	18	4
Omaha	41	33	10	8	3	2	1
St. Louis							
Scranton	28	31	17	10	7	6	1
Washington	9*	10*	24	30†	19†	6	3

1891.

City.	Passing							Ret. 10
	200	70	50	40	30	20	10	
Boston	5	38	19	11	10	10	8†	0
Buffalo 1–B	9	45	32	6	3*	1*	2*	1
Chicago	4	11	24	21	18	12	9	1
Kansas City	3	21	18	14	17	14†	12†	1
Louisville								
Newark	4	9*	11	10	18	23†	23†	3
New Orleans								
New York	4	23	21	16	16	10	9	2
Omaha	3	16*	20	18	27	11	5	0
St. Louis								
Scranton	5	23	16	16	14	16†	11†	0
Washington	4	3*	13*	26	29†	16†	7	1

* Too low. † Too high.

MINERAL AGGREGATE.

1892

City.	Passing							Ret. 10
	200	70	50	40	30	20	10	
Boston	18	21	11	14	14	16†	6	1
Buffalo 1-B	13	53	16	9	3	3	3	3
Chicago	12	29	27	16	9	6	3	0
Kansas City	7	6*	7	13	20	28†	18†	3
Louisville	12	21	20	25	13	6	3	0
Newark	7	11*	17	22	20	18	6	1
New Orleans	6	0*	11	39	32	11	2	1
New York	12	21	13	14	15	15	10	3
Omaha	6	17	10	13	15	21†	17†	2
St. Louis	7	13*	6	13	22	29†	12†	0
Scranton								..
Washington	9	6	8	30	33	12	2	0

1893.

Boston	......	22	16	17	22†	20†	5	
Buffalo	......	51†	27	12	5	3	2	
Chicago	......	47	26	14	7	3	3	
Kansas City	......	41	16	13	11	10	10†	
Louisville								
Newark	......	16*	12	17	18	23	14	
New Orleans								
New York	......	24	10	14	19	19†	14†	
Omaha	......	31	17	13	14	14†	11†	
St. Louis	......	28	14	15	17	17†	9	
Scranton								
Washington	......	20*	13	23	26	13†	6	

1894.

City.	Passing							Ret. 10
	100	70	50	40	30	20	10	
Boston	16	22	25	15	14	8	2	
Buffalo	17	30	34	12	4	2	2	
Chicago	15	19	33	14	7	5	5	
Kansas City	29	21	24	9	7	5	5	
Louisville								
Newark								
New Orleans								
New York	15	8*	19	13	14	14†	14†	
Omaha	21	28	23	10	8	6	4	
St. Louis								
Scranton	18	15	27	14	9	8	11	
Washington	11	5*	12	20	31†	17†	5	

* Too low. † Too high.

MINERAL AGGREGATE.

1895.

City.	Passing							Ret. 10
	100	70	50	40	30	20	10	
Boston	24	17	21	14	11	8	7	
Buffalo	18	32	30	9	3	4	5	
Chicago	22	19	26	12	6	6	9	
Kansas City	27	19	24	10	7	8	5	
Louisville	17	16	33	14	9	6	4	
Newark	16	12*	17	14	14	14†	14†	
New Orleans	18	14*	25	19	13	8	2	
New York	21	15*	15	12	13	12†	13†	
Omaha	21	22	21	11	9	6	7	
St. Louis								
Scranton	19	12*	21	17	13	11	8	
Washington								

1896.

City.	Passing							
	200	100	80	50	40	30	20	10
Boston	12.1	14.4	14.3	27.0	11.0	9.2	6.0	6.0
Buffalo 1–B	7.4	6.2	20.1	49.3	8.1	3.8	2.1	3.0
Chicago Plt. 1	9.9	13.7	18.8	31.1	9.2	6.5	5.2	5.6
Kansas City	13.7	8.7	17.5	40.6	6.7	5.3	3.6	3.9
Louisville	12.2	5.4*	12.6	53.8	8.1	3.7	2.0	2.1
Newark	11.2	8.9*	10.2	25.0	14.8	12.9	8.4	8.6
New Orleans	11.6	9.4*	11.3	31.6	14.7	12.5	6.0	3.0
New York	14.4	11.6	11.9	25.5	13.3	10.6	6.5	6.2
Omaha	10.6	11.9	20.3	33.8	9.2	6.5	4.1	3.5
St. Louis	15.9	10.4	14.6	36.6	11.4	6.8	2.9	1.2
Scranton	11.0	9.5*	12.3	29.1	15.0	12.3	6.6	4.2
Washington	8.7	6.7*	10.4	31.2	20.1	14.7	5.4	2.8

1897.

Boston	16.5	14.9	12.5	26.6	10.1	8.5	5.2	5.7
Buffalo 1–B	15.3	12.6	16.3	46.3	5.7	2.5*	0.8*	0.5*
Chicago	15.7	16.4	19.5	36.3	5.0	2.7*	2.7	1.7
Kansas City	21.1	14.6	15.3	34.5	5.1	3.6	2.9	2.7
Louisville	14.9	6.4*	10.5	54.4	7.5	3.2	1.8	1.2
Newark	17.3	12.2	9.8*	27.3	10.5	10.9	7.2	4.8
New Orleans	14.1	11.1	9.9*	28.9	13.3	11.6	6.6	4.5
New York	18.4	14.5	13.9	27.7	9.4	8.0	4.6	3.5
Omaha	14.6	14.0	17.5	35.5	7.4	5.6	2.9	2.5
St. Louis	23.2	12.7	18.2	32.1	6.7	3.8	2.0	1.2
Scranton	13.7	9.0	11.5	31.1	12.3	11.8	5.9	4.6
Washington	11.4	8.4	7.5	27.1	17.2	13.4	9.5†	5.4

* Too low. † Too high.

MINERAL AGGREGATE.

1898.

City.	Passing							
	200	100	80	50	40	30	20	10
Boston	16.4	15.2	14.3	28.3	11.0	7.5	4.4	2.9
Buffalo 1–B	15.8	14.3	19.2	40.1	6.1	2.8*	1.6	0.1
Chicago	14.6	17.3	14.8	37.6	9.4	3.4*	2.1	0.7
Kansas City	16.2	13.6	15.6	31.9	8.3	6.5	4.5	3.1
Louisville	16.7	11.8	11.3	34.3	10.9	7.3	3.8	4.0
Newark	12.9	12.5	8.4*	20.6	14.4	12.0	11.6	7.6
New Orleans	12.3	8.7*	11.1	34.6	15.8	11.1	4.1	2.3
New York	15.3	14.6	15.0	25.3	11.2	8.5	6.3	3.9
Omaha	13.0	15.6	19.2	32.9	8.0	5.3	3.6	2.4
St. Louis	14.9	10.9	16.6	41.9	6.4	4.3	3.0	1.9
Scranton	13.8	12.0	11.7	29.7	13.2	9.9	5.6	3.9
Washington	13.8	9.3	8.6	29.1	20.0	10.7	5.2	3.2

1899.

City.	200	100	80	50	40	30	20	10
Boston	16.2	13.6	10.4	24.9	15.7	8.4	6.4	4.4
Buffalo 1–B	14.7	11.8	18.7	41.6	7.0	2.8*	1.9	1.5
Chicago	12.9	16.0	17.3	38.5	8.5	3.1*	2.0	1.6
Kansas City	13.5	10.3	15.5	43.9	7.9	4.0*	3.0	1.9
Louisville	17.4	8.0*	5.1*	41.3	21.6	3.4*	2.0	1.2
Newark	16.2	15.2	10.7	12.9	12.5	10.8	11.7	9.9
New Orleans	14.0	12.4	10.4	28.4	19.0	7.7	5.7	2.4
New York	14.5	14.2	14.1	26.7	13.5	7.4	5.9	3.7
Omaha	14.8	14.7	13.9	28.6	12.9	6.3	5.2	3.6
St. Louis	13.8	13.7	12.3	33.2	12.7	6.0	4.8	3.5
Scranton	14.5	12.9	12.2	25.6	16.7	8.6	5.8	3.7
Washington	14.2	8.5*	5.8*	19.5	22.4	11.2	9.8	8.5†

* Too low. † Too high.

Bitumen in the Surface Mixtures of the Earlier Days of the Industry.—Up to 1896 the bitumen in surface mixtures was very variable in amount, and, as a rule, too low, owing probably to the necessity of keeping it at such a point because of the poor sand grading and the absence of binder, to avoid displacement of the street surfaces. The following tables show the average and extreme per cents of bitumen in the surfaces laid by the Barber Asphalt Paving Company in a number of cities during the earlier years of which records are available.

AVERAGE AND EXTREME PERCENTAGES OF BITUMEN IN SURFACES OF THE BARBER ASPHALT PAVING COMPANY FOR ELEVEN YEARS, 1889–1899.

City.	1889	1890	1891	1892	1893
Boston	9 3–10.9 10.0	....	8.9–14.5 11.1	8.6–12.0 10.2	9.3–10.3 9.8
Buffalo	8.4–12.2 9.8	7.6–12.2 10.2	8.1–12.5 10.0	7.2–15.9 10.1	8.1–13.7 10.3
Chicago	8.6–10.5 9.8	9.0–11.5 10.1	7.9–11.7 9.5	8.8–11.5 10.1	9.2–11.7 10.3
Kansas City	8.0–12.3 9.9	8.0–11.1 9.3	7.7–11.7 10.2	8.9–12.3 10.3	9.0–11.3 10.2
Louisville	10.4–11.5 10.7	7.8–10.7 9.3	10.1–12.1 10.9	8.9–10.8 9.6	
Newark	6.7–10.7 9.0	....	6.9–13.0 9.6	7.8–10.9 9.8	9.2–10.2 9.7
New Orleans	8.1–10.6 9.2	....	....	8.8–10.4 9.5	
New York	8.4–12.9 10.8	8.6–12.7 10.8	7.9–13.1 10.6	8.3–11.7 10.1	8.9–13.4 10.5
Omaha	8.5–11.0 9.8	8.6–12.4 10.2	8.0–11.6 9.8	7.7–11.5 9.4	8.8–9.8 9.4
St. Louis	9.6–11.2 10.1	....	....	9.6–12.8 9.7	7.3–11.7 9.7
Scranton	8.5–11.2 10.1	8.8–11.6 10.6	8.2–14.2 10.5	9.2–12.2 10.6	
Washington	8.8–15.5 9.8	9.1–11.4 10.2	8.7–11.5 10.3	8.8–12.8 10.7	9.6–10.9 10.2
Average	9.9	10.1	10.2	10.0	10.0

City.	1894	1895	1896	1897	1898	1899
Boston	8.4–10.0 9.4	7.5–11.1 9.9	8.7–11.1 9.9	9.0–11.0 10.1	9.3–11.3 10.6	9.4–11.5 10.7
Buffalo	6.9–11.9 10.0	8.3–10.6 9.4	8.7–10.6 9.7	9.3–11.3 10.4	9.6–11.2 10.4	8.6–11.6 10.4
Chicago	8.2–11.7 9.8	8.4–11.0 9.9	8.5–11.6 10.2	9.4–11.8 10.8	9.8–11.3 10.5	9.2–11.7 10.6
Kansas City	8.0–12.1 9.9	8.3–10.7 9.3	8.4–10.8 9.4	9.5–11.3 10.4	9.3–11.7 10.4	9.3–11.3 10.4
Louisville	....	8.0–11.6 10.0	9.1–11.4 10.3	9.2–10.5 9.8	9.2–10.7 9.9	9.5–11.7 10.7
Newark	....	7.8–10.6 9.3	9.3–11.6 10.3	8.0–11.3 10.2	9.1–11.1 10.2	9.3–10.6 9.9
New Orleans	8.5–10.2 9.4	9.1–10.9 10.0	9.0–11.7 10.2	9.0–11.9 10.1	9.3–10.7 10.0	9.0–11.6 10.3
New York	8.4–11.7 10.1	7.9–11.3 9.9	9.2–11.6 10.5	9.6–12.3 10.7	9.3–11.4 10.5	9.0–12.1 10.5
Omaha	8.1–9.9 9.0	7.4–10.9 9.1	7.3–10.4 9.4	8.1–11.6 9.1	7.9–11.1 9.0	8.2–11.1 9.5
St. Louis	....	....	9.0–11.3 9.9	9.4–11.6 10.5	10.4–12.5 11.3	9.9–11.3 10.7
Scranton	9.9–11.9 10.6	8.5–10.3 9.4	9.3–11.2 10.2	10.0–11.2 10.4	10.0–11.2 10.2	9.4–11.6 10.4
Washington	10.1–11.0 10.5	....	9.2–12.0 10.8	9.1–12.0 10.8	11.5–13.2 12.1	9.7–13.0 10.8
Average	9.9	9.6	10.1	10.3	10.4	10,4

Since 1896 these irregularities in bitumen have grown smaller and the average percentage of bitumen higher, as can be seen from the average percentage of bitumen in the mixtures laid under the author's supervision as long ago as 1897:

AVERAGE COMPOSITION, SURFACE MIXTURES, 1897.

City.	Bitumen.	Passing Mesh.								Average Penetration of A. C.
		200	100	80	50	40	30	20	10	
St. Louis, Mo.	10.5	20.8	11.4	16.3	28.7	6.0	3.4	1.8	1.1	63°
Kansas City, Mo.	10.4	18.9	13.1	13.7	30.9	4.6	3.4	2.6	2.5	61°
Elmira, N. Y.	10.9	8.9	23.0	25.6	27.8	2.4	1.0	0.3	0.1	75°
Chicago, Ill.	10.8	14.0	16.4	16.5	32.4	4.5	2.4	1.5	1.5	56°
New York, N. Y.	10.7	16.4	12.9	12.4	24.7	8.4	7.1	4.1	3.2	58°
Buffalo, N. Y., 4-B Plt.	10.1	14.0	15.2	14.4	38.7	4.9	1.9	0.6	0.3	61°
" " 3-B "	10.0	14.8	14.2	11.1	38.2	7.1	2.5	0.8	0.7	67°
Niagara Falls, N. Y.	10.2	14.5	13.9	13.2	37.5	6.9	2.9	0.6	0.2	63°
Boston, Mass.	10.1	14.8	13.4	11.2	23.9	9.1	7.6	4.7	5.2	59°
New York, N. Y., Bronx.	10.1	14.2	12.5	9.2	24.6	10.8	10.2	5.6	2.8	62°
Yonkers, N. Y.*	10.5	14.6	12.1	10.7	25.3	9.7	7.5	4.3	4.7	58°
Newark, N. J.	10.2	15.5	10.9	8.8	24.5	9.4	9.8	6.5	4.3	58°
Jersey City, N. J.	11.4	14.6	11.4	13.9	26.7	8.8	6.3	4.0	2.9	55°
Sioux City, Iowa.	10.5	16.0	9.7	9.8	28.7	9.2	8.1	4.2	3.7	61°
Saginaw, Mich.	10.0	13.1	12.1	7.8	29.7	15.6	8.7	2.1	1.0	56°
Buffalo, N. Y., 1-B Plt.	10.4	13.7	11.5	14.6	41.5	5.1	2.1	0.7	0.4	61°
New Orleans, R.R. Plt.	10.6	14.5	9.9	10.8	21.7	11.2	10.2	6.5	4.6	51°
Detroit, Mich.	10.8	12.4	11.3	13.7	41.2	4.3	2.4	1.7	2.2	57°
Pittston, Pa.	10.6	11.3	11.9	12.8	32.8	7.6	7.1	3.2	2.6	51°
New Orleans, La.	10.1	12.7	10.0	8.9	25.9	11.9	10.4	5.9	4.1	45°
Wilkesbarre, Pa.	10.5	12.8	8.2	8.5	26.6	13.7	9.7	6.3	3.7	51°
Rockford, Ill.	10.1	13.2	7.6	7.3	30.5	15.6	12.2	2.7	0.8	54°
Scranton, Pa.	10.4	12.3	8.1	10.3	27.9	11.0	10.6	5.3	4.1	57°
Harrisburg, Pa.	10.3	13.1	6.9	5.0	34.1	19.9	6.8	2.8	1.1	63°
Washington, D. C.	10.8	10.2	7.5	6.7	24.2	15.4	12.0	8.5	4.8	60°
Akron, Ohio.	11.1	10.9	6.4	12.7	41.0	8.6	5.9	1.9	1.4	57°
Average.	10.5	....	....	....	....	....	....	....	....	58°

*Retained on 10-mesh, .5%.

Experience has shown, however, that in these surfaces, although the average percentage of bitumen reached 10.5, it was in most cases too hard, averaging 58, which has resulted in some cracking. In subsequent years, therefore, it has been the practice to use softer asphalt cement. The results have been very satisfactory.

Too small an amount of bitumen in a mixture permits the easy entrance or absorption of water, which eventually disintegrates and rots the surface. It reduces the tensile strength and prevents the accommodation of the surface to the contraction of the mineral aggregate, which follows a rapid fall of temperature, as this can only be met by the elongation of the bitumen. In both of these ways lack of bitumen is a direct cause of cracking and deterioration of pavements.

Analyses of specimens of old surface from Omaha, grouped and arranged according to their condition, show that the badly cracked pavements in that city contain the least bitumen and the better pavements the most, as appears from the following figures:

AVERAGE BITUMEN IN OMAHA ASPHALT SURFACES.

Good	10.0%
Medium	9.4
Badly cracked	8.6

The results of the examination of the surfaces collected in 1894 and of the data available at that time having shown nothing more than the fact that there was no uniformity in the way the mixture was made before then, and that it would be necessary to extend the investigation still further to find which was the most desirable composition, this work was continued as opportunity offered during a period extending over two years and with extremely interesting results, which were published in Bulletin No. 1 of the Office of the Superintendent of Tests of the Barber Asphalt Paving Company, in March 1896, the substance of which was as follows:

"The attention of the author was attracted, as long ago as 1889, to a particularly good asphalt surface on Vermont Avenue, in Washington, D. C., which, although subjected to light traffic, had had scarcely a repair after, at that time, ten years' service. An analysis of this surface gave the following results:

"Bitumen	11.3%
Passing 200-mesh sieve	16.0
" 100- " "	8.7
" 80- " "	5.2
" 50- " "	32.0
" 40- " "	16.4
" 30- " "	6.0
" 20- " "	2.7
" 10- " "	1.7
	100.0
Density	2.18

"The high percentage of bitumen and of dust, both unusual at the time the surface was examined, led to the conclusion that the desirable properties of this surface were due to the presence of plenty of bitumen and dust. In order to confirm this, several other surfaces were selected in Washington which were typically good or bad, and it was found that the best were characterized by a similar composition to that of the Vermont Avenue surface, while the inferior were deficient in both asphalt cement and dust. An inquiry as to the conditions under which the Vermont Avenue surface was laid showed that the sand in use was from a pit and contained much fine material, on which account it was eventually abandoned.

"In 1893 attention was called to the excellent character of the asphalt surface on Court Street in Boston, which had sustained successfully a very heavy traffic. The surface mixture was examined by the author and found to have the following composition:

"Bitumen	11.7%
Passing 200-mesh sieve	14.5
" 100- " "	11.2
" 80- " "	24.1
" 50- " "	20.5
" 40- " "	5.8
" 30- " "	4.6
" 20- " "	4.0
" 10- " "	3.6
	100.0

"In this mixture high percentages of bitumen, of dust and of fine sand were found, which was in confirmation of the original conclusion that the Vermont Avenue surface in Washington wore well because it contained high percentages of these materials. These results led to the suggestion that the inquiry should be extended to a collection of representative surfaces from various parts of the country. This was undertaken and led to the same general conclusion, namely, that surfaces carrying the most bitumen and dust or filler are the most satisfactory.

"In 1895 the inquiry was extended still further, and an examination of the street surfaces laid in a western city during the period extending from 1888 to that year, some of which were much more satisfactory than others, was made. The results of the analyses of surfaces representing different years' work were as follows:

	1888	1889	1890	1891	1892	1893	1894	1895
“Bitumen................	9.85	10.35	9.35	9.05	10.55	9.85	9.35	9.50
Passing 200-mesh sieve....	9.00	9.60	7.50	10.60	9.25	9.00	11.40	10.95
“ 100- “ “	8.80	25.45	10.10	9.60	5.80	6.30	16.60	13.95
“ 80- “ “	10.20	23.05	10.50	14.50	6.65	5.40	16.30	17.50
“ 50- “ “	26.00	20.05	20.00	30.20	26.50	36.30	21.50	31.00
“ 40- “ “	12.30	4.55	12.70	8.20	14.40	10.80	6.10	4.95
“ 30- “ “	11.90	4.05	13.90	6.90	12.55	8.20	7.80	6.40
“ 20- “ “	6.60	2.80	7.60	5.00	8.25	6.50	6.00	2.70
“ 10- “ “	3.35	2.10	8.35	5.95	6.05	7.65	4.95	3.08

“If these results are grouped more closely, calling 200-mesh material dust, 100- and 80-mesh material fine sand, 50- and 40-mesh medium, and 30-, 20-, and 10-mesh coarse sand, the analyses catch the eye more quickly.

	1888	1889	1890	1891	1892	1893	1894	1895
“Bitumen................	9.85	10.35	9.35	9.05	10.55	9.85	9.35	9.50
Dust......................	9.00	9.60	7.50	10.60	9.25	9.00	11.40	10.95
Fine sand................	19.00	46.50	20.60	24.10	12.45	11.70	32.90	31.45
Medium sand............	40.30	24.60	32.70	38.40	40.90	47.10	27.60	35.95
Coarse sand..............	21.85	8.95	29.85	17.85	26.85	22.35	18.75	12.18

“The characteristics of these surfaces as noted on the streets were:

“1888........Soft; pushes and calks.
1889........Considered one of the best mixtures.
1890........Calks badly.
1891........Calks badly.
1892........Calks badly.
1893........Calks worst of all; very mushy.
1894........Hardly marked; very stable.

“The 1894 mixture is the only one which has produced a surface which is reasonably free from calking in hot weather. Of the

1895 surfaces we cannot judge until another year, although they at present are very promising and probably quite as good as those of 1894.[1] The 1889 surfaces are in better form than the surfaces of years prior to 1894. Those of 1891, 1892, and 1893 are so yielding as to be a mass of calk marks in summer. How this occurs is seen from the differences which are brought out by analyses. The 1888, 1890, 1891, 1892, and 1893 surfaces are deficient in fine sand as compared to those of 1894, and this is especially the case with those of 1892 and 1893, where there is but 12.45 and 11.70 per cent, respectively, of fine material. They do not carry enough sand grains of this size to make the surface dense, and of course conversely they have too much coarse material. It is apparent, therefore, that, with the available sand, the grading must be so arranged that the coarse part shall not run as high as 20 per cent, preferably about 15 per cent, and the fine shall reach about 30 per cent, the dust being about 11 per cent, to give a stable surface. The bitumen in these mixtures is too low when compared with the amount found necessary for good surfaces in most cities, but here it was due to peculiarities in the sand, owing to which it will not carry more, and is therefore not as serious a defect as it would be in some other places.

"As a whole the experience in this city was very encouraging in its confirmation of previous conclusions, and sufficiently so to render an attempt to follow them out in practice in other places desirable."

The bulletin then goes on to present two illustrative cases where an explanation had been sought for the good or bad wearing properties of asphalt surfaces:

"In New York there has been during the present winter (1896) some scaling of surfaces laid in the autumn of 1895, whereas others have shown nothing but the best results. Typical of these were surfaces on Fifth Avenue at Fifty-ninth Street and on Eighth Avenue at Twenty-eighth Street. Analyses were made of specimens of these surfaces, which quickly explained the differences in behavior. The results were as follows:

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[1] At the present time it can be seen that the mixtures of 1895 have proved as desirable as it was expected they would.

NEW YORK MIXTURE LAID IN 1895.

	Per Cent.		Per Cent.	
"Bitumen	9.8		11.1	
Passing 200-mesh sieve	7.3		9.8	
" 100- " "	5.9	14.7	11.1	18.6
" 80- " "	8.8		7.5	
" 50- " "	24.4		28.6	
" 40- " "	12.4		6.6	
" 30- " "	9.1	30.6	10.3	25.3
" 20- " "	10.7		8.0	
" 10- " "	10.8		7.0	
Retained on 10-mesh sieve	.8			
	100.0		100.0	

"The same striking contrast between a good surface and a poor one is here again well illustrated in the difference in bitumen and fine material in the two specimens.

"Again the unsatisfactory surfaces from St. Louis, samples of which were sent in recently for examination, show that a coarse mixture is an inferior one and likely to scale. The results of an examination of the St. Louis surfaces were as follows. See results given in first two tables on page 327.

"In this way the original conclusions of earlier years have been confirmed, and it has become the present policy to work upon the lines above indicated in laying surface. While nothing absolutely fixed can be suggested as a universal mixture, perhaps for the present the following may be considered as an ideal towards which to work.

"Bitumen	10.0%	or above
Passing 200-mesh sieve	10.0%	" "
" 100- " "	10.0%	" "
" 80- " "	20.0%	" "
" 50- " "	24.0%	" "
" 40- " "	10.0%	" "
" 30- " "	8.0%	" "
" 20- " "	5.0%	" "
" 10- " "	3.0%	" "

"The grading should not, apparently, be stretched too far as in such a case but little asphalt cement can be gotten in, and the surface will lack elasticity.

ST. LOUIS SURFACES OF 1892.

	Per Cent.		Per Cent.	
"Bitumen	9.7		10.0	
Passing 200-mesh sieve	7.2		7.1	
" 100- " "	6.7	10.0	7.3	17.8
" 80- " "	3.3		10.5	
" 50- " "	6.9		19.0	
" 40- " "	9.7		8.4	
" 30- " "	17.7	56.5	13.9	37.7
" 20- " "	20.2		12.4	
" 10- " "	18.6		11.4	
	100.0		100.0	

ST. LOUIS SURFACES OF 1893.

	Per Cent.		Per Cent.		Per Cent.		Per Cent.		Per Cent.	
"Bitumen.	9.2		10.6		9.4		10.2		9.3	
Passing 200	2.8		5.5		7.0		6.3		6.6	
" 100	9.6	19.0	4.8	13.0	5.0	13.8	5.6	9.9	5.6	9.3
" 80	9.4		8.2		8.8		4.3		3.7	
" 50	37.0		27.3		17.8		18.4		10.2	
" 40	10.7		11.1		11.1		12.7		10.0	
" 30	10.8	21.3	15.3	32.5	18.1	40.9	15.5	42.5	21.1	54.6
" 20	5.7		9.6		15.5		13.2		20.4	
" 10	4.8		7.6		7.3		13.8		13.1	
	100.0		100.0		100.0		100.0		100.0	

" Finally, it must be remembered that many mixtures which are quite different from the fine ones which have been mentioned have furnished good surfaces for light traffic. In Washington, D. C., for instance, a recent mixture (1896) analyzed as follows, and will, no doubt, serve entirely well there:

"Bitumen	11.4%
Passing 200-mesh sieve	7.2
" 100- " "	2.9
" 80- " "	3.1
" 50- " "	14.4
" 40- " "	16.9
" 30- " "	19.1
" 20- " "	16.4
" 10- " "	8.6
	100.0

" In the same way many coarse streets in Buffalo have served as well as could be desired.

"In conclusion, attention must be called to the fact that a high percentage of bitumen is not safe in a mixture which is deficient in dust and fine sand, especially when it is to meet heavy traffic, because such a surface is unstable without the material which gives it stiffness and capacity to resist pushing and marking. This is the reason the use of large percentages of asphalt cement in some cases has been the cause of trouble and has led to the use of mixtures deficient in asphalt cement for streets of heavy traffic. In most cases, with plenty of dust and fine sand, the per cent of asphalt cement in the mixture with steam refined Trinidad asphalt can be carried well above 15 per cent.

"CLIFFORD RICHARDSON,
"Superintendent of Tests.

"Long Island City, N. Y., March 10, 1896."

Soon after the appearance of this bulletin the author carried out the ideas contained in it in laying a Trinidad lake asphalt pavement, on the King's Road in Chelsea, London, England. The composition of this mixture was as follows:

Bitumen	10.8%
Passing 200-mesh sieve	13.6
" 100- " "	7.3
" 80- " "	22.5
" 50- " "	25.5
" 40- " "	8.9
" 30- " "	6.6
" 20- " "	3.0
" 10- " "	1.8
	100.0

As this surface resisted entirely successfully the heavy traffic and fogs of London, where previous attempts with coarser sand and less filler had failed, it seemed to settle the fact that the conclusions drawn in the bulletin were correct, and from that time to the present all the work under the supervision of the author on streets of much travel has been done with surface mixtures made on these lines.

After the London work the next important surface which was laid was that on Fifth Avenue, in New York. This has proved successful. Its average composition is as follows:

	Bitumen.	Passing Mesh							
		200	100	80	50	40	30	20	10
1896.....	10.8	15.4	10.5	10.7	22.3	10.9	8.9	4.9	5.6
1897.....	10.6	17.4	12.3	11.1	23.3	8.8	8.0	4.7	3.7
FOR COMPARISON.									
London. .	10.8	13.6	7.3	22.5	25.5	8.9	6.6	3.0	1.8

After from twelve to thirteen years' use the surfaces laid in London and that on Fifth Avenue, New York, have proved themselves most satisfactory.

Since the year 1896 the asphalt pavements laid by the Barber Asphalt Paving Company have been constructed, as a rule, in a similar way to that which has been described; but there has been a decided improvement in the character of the work with each succeeding year, as can be seen by comparing the average composition of mixtures laid in 1896 in several important cities with those laid in the same places in 1899 and in 1904.

BITUMEN AND MINERAL AGGREGATE.

1896.

City.	Bitumen.	Passing Mesh							
		200	100	80	50	40	30	20	10
Boston............	9.9	10.9	13.0	12.9	24.4	9.9	8.3	5.4	5.4
Buffalo 1-B........	9.7	6.7	5.6	18.1	44.4	7.3	3.4	1.9	2.7
Chicago Plt. 1.......	10.2	8.9	12.3	16.9	27.9	8.3	5.8	4.7	5.0
Kansas City.......	9.4	12.4	7.9	15.8	36.7	6.1	4.8	3.3	3.5
Louisville..........	10.3	10.9	4.9	11.3	48.3	7.3	3.3	1.8	1.9
Newark...........	10.3	10.0	8.0	9.1	22.4	13.3	11.6	7.5	7.7
New Orleans.......	10.2	10.4	8.4	10.1	28.3	13.2	11.2	5.4	2.7
New York.........	10.5	12.9	10.4	10.6	22.8	11.9	9.5	5.8	5.5
Omaha............	9.4	9.6	10.8	18.4	30.6	8.3	5.9	3.7	3.2
St. Louis..........	9.9	14.3	9.4	13.3	33.0	10.3	6.1	2.6	1.1
Scranton..........	10.2	9.9	8.5	11.0	26.1	13.5	11.0	5.9	3.8
Washington........	10.8	7.8	6.0	9.3	27.8	17.9	13.1	4.8	2.5
Average per cent...	10.1								

BITUMEN AND MINERAL AGGREGATE.

1897.

City.	Bitumen.	Passing Mesh							
		200	100	80	50	40	30	20	10
Boston	10.1	14.8	13.4	11.2	23.9	9.1	7.6	4.7	5.2
Buffalo 1–B	10.4	13.7	11.5	14.6	41.5	5.1	2.1	0.7	0.4
Chicago	10.8	14.0	16.4	16.5	32.4	4.5	2.4	1.5	1.5
Kansas City	10.4	18.9	13.1	13.7	30.9	4.6	3.4	2.6	2.5
Louisville	9.8	13.4	5.8	9.5	49.1	6.8	2.9	1.6	1.1
Newark	10.2	15.5	10.9	8.8	24.5	9.4	9.8	6.5	4.3
New Orleans	10.1	12.7	10.0	8.9	25.9	11.9	10.4	5.9	4.1
New York	10.7	16.4	12.9	12.4	24.7	8.4	7.1	4.1	3.2
Omaha	9.1	13.3	12.7	15.9	32.3	6.7	5.1	2.6	2.3
St. Louis	10.5	20.8	11.4	16.3	28.7	6.0	3.4	1.8	1.1
Scranton	10.4	12.3	8.1	10.3	27.9	11.0	10.6	5.3	4.1
Washington	10.8	10.2	7.5	6.7	24.2	15.4	12.0	8.5	4.8
Average per cent	10.3								
1898.									
Boston	10.6	14.7	13.6	12.8	25.3	9.8	6.7	3.9	2.6
Buffalo 1–B	10.4	14.1	12.6	17.2	35.9	5.5	2.5	1.4	0.1
Chicago	10.5	13.2	15.5	13.2	33.6	8.4	3.0	1.9	0.6
Kansas City	10.4	14.6	12.4	14.0	28.6	7.4	5.8	4.0	2.8
Louisville	9.9	15.0	10.6	10.2	30.9	9.8	6.6	3.4	3.6
Newark	10.2	11.6	11.2	7.5	18.5	12.9	10.6	10.4	6.8
New Orleans	10.0	11.1	7.8	10.0	31.1	14.2	10.0	3.7	2.1
New York	10.5	13.7	13.1	13.4	22.6	10.0	7.6	5.6	3.5
Omaha	9.0	11.8	14.2	17.5	29.9	7.3	4.8	3.3	2.2
St. Louis	11.2	13.2	9.7	14.7	37.2	5.7	3.8	2.7	1.7
Scranton	10.2	12.4	10.8	10.5	26.6	11.8	8.9	5.2	3.5
Washington	12.1	12.1	8.2	7.6	25.6	17.6	9.4	4.6	2.8
Average per cent	10.4								
1899.									
Boston	10.7	14.5	12.1	9.3	22.2	14.0	7.5	5.7	4.0
Buffalo 1–B	10.4	13.2	10.6	16.7	37.3	6.3	2.4	1.7	1.3
Chicago	10.6	11.5	14.3	15.5	34.5	7.6	2.8	1.8	1.4
Kansas City	10.4	12.1	9.2	13.9	39.3	7.1	3.6	2.7	1.7
Louisville	10.7	15.5	7.1	4.6	36.9	19.3	3.0	1.6	1.1
Newark	9.9	14.8	13.7	9.6	11.6	11.3	9.7	10.5	8.9
New Orleans	10.3	12.6	11.1	9.3	25.5	17.0	6.9	5.1	2.2
New York	10.5	13.0	12.7	12.6	23.9	12.1	6.6	5.3	3.3
Omaha	9.5	13.4	13.3	12.6	25.9	11.7	5.6	4.7	3.3
St. Louis	10.7	12.3	12.2	11.0	29.7	11.3	5.4	4.3	3.1
Scranton	10.4	13.0	11.6	10.9	22.9	15.0	7.7	5.2	3.3
Washington	10.8	12.7	7.6	5.2	17.4	20.0	10.0	8.7	7.6
Average per cent	10.4								

AVERAGE COMPOSITION SURFACE MIXTURE. 1904.

City.	Bitumen.	Passing Mesh								Retained 10.	Average Penetration of A. C.
		200	100	80	50	40	30	20	10		
Alexandria, La. . . .	10.0%	11.0%	18%	7%	19%	15%	13%	5%	2%	. . .	55°
Allegheny, Pa.	11.2	12.8	5	9	42	11	4	3	2	. . .	62
Auburn, Ind.	10.5	12.5	13	12	28	9	6	4	5	. . .	68
Boston, Mass.	11.2	12.8	10	12	32	12	5	3	2	. . .	64
Buffalo, N. Y.	10.4	17.6	12	9	25	7	4	3	7	5%	62
Chicago, Ill.	10.5	11.5	16	17	34	5	2	2	2	. . .	61
Cincinnati, Ohio. . .	10.2	12.8	11	13	29	13	6	3	2	. . .	54
Decatur, Ill.	11.4	15.6	10	8	27	11	6	5	5	1	63
Des Moines, Iowa. .	11.0	12.0	9	16	30	9	8	3	2	. . .	71
Detroit, Mich.	10.7	10.3	12	12	33	10	7	3	2	. . .	72
Ft. Dodge, Iowa. . .	10.9	12.1	12	13	27	13	6	3	2	1	64
Ft. Wayne, Ind. . . .	10.6	11.4	11	12	27	14	7	5	2	. . .	66
Grand Rapids, Mich.	10.2	11.8	11	10	23	12	11	6	4	1	62
Harrisburg, Pa.	10.6	13.4	6	8	32	15	7	5	3	. . .	66
Kansas City, Mo. . .	10.3	21.7	18	13	16	6	6	6	3		
New York, N. Y. . .	10.9	14.1	11	10	28	13	7	4	2	. . .	68
Los Angeles, Cal. . .	11.0	12.0	14	12	20	11	8	8	4		
Louisville, Ky.	11.2	15.8	12	8	26	13	7	4	3	. . .	53
New Albany, Ind. . .	10.8	17.2	7	5	23	17	12	6	2	. . .	65
New Orleans, La. . .	10.1	10.9	15	13	23	14	8	4	2	. . .	54
Niagara Falls, N. Y.	10.3	12.7	11	13	26	10	9	3	4	1	67
Omaha, Neb.	10.9	13.1	7	13	39	6	4	4	3	. . .	69
Ottawa, Ont.	10.6	15.3	20	11	27	7	4	4	1	. . .	58
Pittsburg, Pa.	10.4	12.6	7	6	42	12	5	3	2	. . .	67
Sandusky, Ohio. . . .	10.4	8.6	13	12	28	12	7	5	4	. . .	67
Seattle, Wash.	12.3	12.7	14	11	25	11	7	4	3	. . .	80
Spokane, Wash. . . .	12.9	11.1	14	11	22	8	9	7	5	. . .	77
St. Louis, Mo.	11.3	15.7	15	14	27	6	5	4	2	. . .	75
St. Paul, Minn.	10.9	14.1	12	14	31	10	5	2	1	. . .	74
Tacoma, Wash.	11.9	12.1	13	10	24	13	8	5	3	. . .	76
Toronto, Ont.	10.7	16.3	21	14	27	6	3	1	1	. . .	61
Trenton, N. J.	10.5	10.5	9	14	29	14	8	3	2	. . .	73
Walla Walla, Wash.	13.4	7.6	14	12	27	8	8	9	1	. . .	80
Wichita, Kan.	10.3	11.7	10	16	32	10	5	3	2		
Average.	10.9										66

The general improvement and greater uniformity reached by experience between 1896 and 1899 and 1899 and 1904 is marked in several particulars. The average per cent of bitumen in the more recent mixtures is at a far better figure, 10.9, because the grading in the later mineral aggregate is more satisfactory, since it holds more 200-mesh dust and, as a rule, a better percentage of 100- and 80-mesh sand. In some cases, of course, the sand grading could still be improved upon in this direction, but this is the case only where no suitable fine sand was available within reasonable distances, as in Washington and Louisville, while a falling off of the 100- and 80-mesh grains in New York in 1904 is due to inability to find such sand, this material being derived in 1899 from ballast coming to the port, none of which is now to be had. The New York surface mixture of 1904 is, therefore, not as satisfactory as it was in the former years.

The New York mixture of 1899 was regarded at that time as an unexceptional one, and it was decided to consider it a standard for mixtures on streets of any traffic for the remainder of the country. In round numbers the composition of this mixture and of the sand of which it was composed, regardless of the small amount of 200-mesh material which it contained, was as follows:

		Sand.
Bitumen	10.5%	
Passing 200-mesh sieve	13.0	
" 100- " "	13.0	17.0%
" 80- " "	13.0	17.0
" 50- " "	23.5	30.0
" 40- " "	11.0	13.0
" 30- " "	8.0	10.0
" 20- " "	5.0	8.0
" 10- " "	3.0	5.0
	100.0	100.0

With the object of explaining to the practical man, the superintendent or yard foreman, the features of such a standard mixture it was considered from the point of view of consisting of a mineral aggregate composed of sand and dust and a proper percentage of bitumen. The mineral aggregate must be regarded as being made up of three elements—the fine sand, which is the most important, the coarse sand, which is desirable, and the dust or filler, which is absolutely necessary. The mineral aggregate of a standard mixture may, therefore, be considered from the following points of view:

1st point—100- and 80-mesh sand	17+17=34%
2d " —10-, 20-, and 30-mesh sand	10+8+5=23
3d " —Filler+200 sand. Dust+fine sand	=17

Or for the complete surface mixtures:

1st point	—100 and 80 sand	13+13=26%
2d "	—10, 20, and 30 sand	3+5+8=16
3d "	—Filler+200 sand	=13
4th "	—Bitumen	=10.5

Or these points may be expressed in one of the following ways.

ASPHALT SURFACE MIXTURE.

- Correct surface mixture, 100%
  - Bitumen 10.5% (4th point)
  - Mineral aggregate, 89.5% (1st point) (2d ") (3d ")
    - Filler, 13.0% (3d point)
    - Sand, 76.5% (1st point) (2d ")
      - Mesh.
      - 100..13.0 } 26.0%
      - 80..13.0 } 26.0% (1st point)
      - 50........23.5%
      - 40........11.0%
      - 30...8.0 } 16.0%
      - 20...5.0 } 16.0%
      - 10...3.0 } 16.0% (2d point)

ASPHALT SURFACE MIXTURE.

Composition.				
Bitumen	10.5—4th point			Correct asphalt mixture, 100%
Filler+200 sand	13.0—3d point		Mineral aggregate, 89.5%	
100 sand, 13.0 80 " 13.0	26.0—1st point	Sand, 76.5%		
50	23.5			
40	11.0			
30...... 8.0 20...... 5.0 10...... 3.0	16.0—2d point			

The surface mixture, therefore, may be regarded:

1st. As a whole.

2d. As a mixture of bitumen and a mineral aggregate.

3d. As a mixture of bitumen, filler, and sand.

4th. As a mixture of bitumen, filler, 100- and 80-mesh sand and 10-, 20-, and 30-mesh sand in suitable proportions.

For example take a New York mixture:

1st. New York mixture.

2d. 10.5 per cent bitumen, 89.5 per cent mineral aggregate.

3d. 10.5 per cent bitumen, 13.0 per cent dust, 76.5 per cent sand.

4th.	Bitumen,	200 Dust,	100	80	50	40	30	20	10
	10.5	13.0	26.0		23.5	11.0	16.0		
or									
	10.5	13.0	13.0	13.0	23.5	11.0	8.0	5.0	3.0

In forming an opinion, therefore, of an old or new surface mixture it becomes evident that the four points which have been described must be considered. These points may be differentiated from the composition of an old mixture or combined to form a new one.

The primary consideration is the sand and the *first point* that it shall contain a normal and sufficient amount of 100- and 80-mesh material. This was, and undoubtedly is to-day, the most essential feature in making a satisfactory mixture. It is essential because without this fine sand the mixture is porous and open, and more particularly because, unless it is present, a sufficient amount of dust or filler cannot be used. The fine sand prevents the dust from balling up and making a lumpy mixture and, as will eventually appear, the larger the amount of fine sand the more dust can be introduced without difficulty. In the earlier mixtures, 1880 to 1896, a large percentage of dust could seldom be used, although the attempt was often made, as the resulting mixture was difficult to handle and rake.

The *second point* or consideration lies also in the sand grading and is the regulation of the amount of the 10-, 20-, and 30-mesh sand grains. In the Fifth Avenue mixture this material amounted to 16 per cent. It was unavoidable there, owing to the character of the sand available, but was believed to be desirable in several ways. In the first place, it seemed to fill the place taken by broken stone in hydraulic concrete, and to carry the traffic, so to speak. In the second place, it gave a less slippery surface than a finer mineral aggregate. In both these ways the coarse material is desirable, but closer study and experience has shown that at times it may be reduced or largely omitted to advantage, especially in damp climates.

To bring about a satisfactory arrangement of the first two points, or sand grading, one or more kinds of sand are necessary, usually more than one. For example, in the Fifth Avenue mixture the main sand supply was deficient in 100- and 80-mesh grains. It was, therefore, necessary to add a certain amount of fine sand consisting predominantly of grains of this size.

The *third point*, and one also of great importance, is that the amount of filler or dust shall be sufficient. In the standard mixture of 1899 this was intended to reach, together with the small amount of 200-mesh sand and the natural filler present in Trinidad asphalt, 13 per cent. In the older, coarse Washington and St. Louis mixtures of the early nineties the filler and 200 sand rarely reached 7 per cent, and in St. Louis fell, at times, below 3 per cent. This was attributable to two causes: one, the fact that such coarse mixtures would not carry much dust without balling, and the other, because it was considered at that time uncertain if there were any merit in using a filler. We now know that dust gives stability to the mixture, aids in excluding water, and that the best surfaces are those which, up to a certain limit, contain the most filler. In the standard mixture of 1899 the largest amount of dust which such a sand grading could carry was about 13 per cent, owing to the relatively small amount of 100 and 80 sand grains. Beyond this percentage the mixtures would become greasy or would ball.

With the first three points arranged in a satisfactory way, the *fourth* or *last point* was to decide on how much asphalt cement the mineral aggregate would carry. This has been determined in recent years by the pat test, described on pages 351 and 514, which readily shows whether an excess or deficiency in asphalt cement has been used. This test cannot, in all probability, be improved upon. If each grain of material in the mineral aggregate is coated with asphalt cement and the voids more than filled the excess will be squeezed out in making a pat and stain the paper excessively. If the voids are not filled the only stain on the paper will be a light one from the cement coating the grains of sand. A perfect mixture will contain just enough cement to fill the voids in the aggregate, stain the paper well but not excessively (Figs. 6, 7, 8, and 9). The hotter the mixture the more liquid the asphalt cement and the freer the stain. Cold mixtures will give no indication, while the difference in the markings of a fine and coarse sand will be readily learned by experience.

The preceding instructions are satisfactory for turning out a mixture for the conditions ordinarily met with if the available materials admit of following them, or for judging the character of old surfaces when they have been resolved into their constituents by analytical methods.

In cases where there may be an excess of fine sand, particularly of 200-mesh material, some modification of the method of procedure which has been described will be necessary. This will be taken up later.[1]

Work on the Old Rule-of-thumb Basis.—In comparison with a standard mixture made according to the previous instructions work done without any rational method of control is instructive. Several such mixtures have been examined which were laid in Chicago in 1898 and 1899 by contractors exercising no technical supervision over their work. See first table on page 337.

There is hardly a mixture among these that is not open to criticism in one respect or another, while that laid under the author's supervision could in itself be slightly improved. The mixtures are more or less deficient in coarse sand as compared with the standard adopted. This is general, if it is a defect, and is due to the character of the local sand. The Bermudez mixture is very deficient in bitumen and for no other reason except that enough asphalt cement has not been put in. It would easily carry more, as the sand is very fine, quite too much so.

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[1] See page 345.

CHICAGO, ILL., MIXTURES OF 1898 AND 1899.

	Bitumen.	Passing Mesh								Retained on 10.
		200	100	80	50	40	30	20	10	
Bermudez asphalt.......	8.9	11.1	20.0	35.0	20.0	1.0	1.0	1.0	1.0	1.0
Trinidad lake asphalt....	11.2	12.8	8.0	11.0	43.0	7.0	4.0	2.0	1.0	
Alcatraz asphalt.........	10.3	13.7	5.0	28.0	37.0	4.0	2.0	0.0	0.0	
Standard asphalt........	8.5	8.5	5.0	28.0	41.0	7.0	2.0	0.0	0.0	
Trinidad land asphalt....	10.8	6.2	18.0	26.0	31.0	5.0	1.0	1.0	1.0	
FOR COMPARISON.										
Author's supervision.....	10.6	11.4	14.0	15.0	35.0	8.0	3.0	2.0	1.0	

The second mixture is one which is hardly open to serious comment. The mineral aggregate should have, however, rather more 80- and 100-mesh grains, so that they should together reach 25 to 27 per cent.

The Alcatraz has only 6 per cent of sand coarser than a 50-mesh sieve, and it is unbalanced in its 80- and 100-mesh sizes.

The Standard mixture is very inferior and cannot prove satisfactory. It is very deficient in bitumen, dust, and 100-mesh sand, three of the important factors in a good wearing surface.

The Trinidad land asphalt should have more filler, but it is not otherwise defective, in so far as the mineral aggregate is concerned, except in the usual absence of coarse sand.

As a whole these mixtures are excellent examples of ordinary work done empirically and without proper control.

In other cities even more glaring defects are often met, as can be seen from a few examples:

Cities.	Bitumen.	Passing Mesh							
		200	100	80	50	40	30	20	10
Toronto, Canada...	8.4*	24.6*	22.0	12.0	22.0	5.0	3.0	2.0	1.0
Utica, N. Y........	8.0*	26.5*	31.7	17.9	7.7	5.6	1.5	0.8	0.3
Indianapolis, Ind...	9.9	13.1	3.0*	3.0*	24.0	22.0	12.0	7.0	6.0

* The shortcomings are here marked with an asterisk.

That the cardinal points in a mixture were often neglected in the earlier days can also be seen from an examination of the materials and their proportions in a mixture sent out on August 8, 1895, for use on Eighth Avenue in New York:

SAND—COW BAY. (GOODWIN.)

Passing 200-mesh sieve	Trace
" 100- " "	"
" 80- " "	"
" 50- " "	5.0%
" 40- " "	13.0
" 30- " "	42.0
" 20- " "	37.0
" 10- " "	2.0

DUST—TUBE-MILL.

Passing 200-mesh sieve	66.0%
" 100- " "	20.0
" 80- " "	14.0

ASPHALT CEMENT.

Bitumen	65.0%

PROPORTIONS.

Sand	801 lbs.	79.5%
Dust	60 "	5.9
A. C.	147 "	14.6
	1008	100.0

A mixture made from the above materials in the proportions given would have about the following composition:

Bitumen	9.5%	—4th point
Passing 200-mesh sieve	8.9	—3d "
" 100- " "	1.3	2.3—1st "
" 80- " "	1.0	
" 50- " "	4.1	
" 40- " "	10.4	
" 30- " "	33.5	64.8—2d "
" 20- " "	29.6	
" 10- " "	1.7	
	100.0	

It is evident that none of the four points in a good mixture is approached in this one. It is deficient in fine sand, far too coarse, contains too little dust, and would not hold enough bitumen.

This is, of course, an exaggerated case, but much mixture of a similar description has been sent out and is being made to-day by ignorant contractors.

Problems Arising from Lack of Sand Suitable for Obtaining the Standard Grade.—Our illustrations and experience have shown that at times the sands to be found in any locality do not permit of attaining the standard grade which has been proposed. For example, in Washington, D. C., there is no sand available which will supply the proper amount of 100- and 80-mesh material in sufficient amount. In other cities there may be an excess of 200-mesh sand. Again, in some localities, coarse sand is an expensive article, and it is impossible to introduce into the mixture the normal amount of 10-, 20-, and 30-mesh grains at any reasonable cost. Finally, questions arise as to whether under some trying conditions a mixture cannot be made which is more resistant to unfavorable environment than the standard and as to whether sands of the same grading in different localities the grains of which may have a different surface and a different shape, and in consequence of the last fact may have different voids, can be handled in the same way as New York sand. The proper amount and the consistency of the asphalt cement to be used under various conditions must also be determined. These points have been so far settled by the results of investigations carried out during the last few years that the problems can now be discussed fairly intelligently.

Mixtures Necessarily Coarser than Standard.—The City of Washington was once in a situation of this kind. Until recent years, there has been no available supply there of what is known as "tempering sand," and the surface mixture in use was on this account deficient, more or less, in 80 and 100 mesh grains. In the early days of the industry this deficiency was a serious one. The average composition of the surface mixture laid in 1889 was as follows:

Density	2.10
Bitumen	9.7%
Passing 200-mesh-sieve	9.3
" 100 " "	3.0
" 80 " "	5.0
" 50 " "	20.0
" 40 " "	20.0
" 30 " "	18.0
" 20 " "	8.0
" 10 " "	7.0
	100.0

This mixture is plainly deficient in 80- and 100-mesh sand grains, in the percentage of bitumen, and probably in filler or actual dust, since less than 4 per cent of ground limestone, of which not more than 60 per cent passes a 200-mesh sieve, was added to the mixture, although the 200-mesh material reaches 9.3 per cent, more of this being in the form of sand grains than of dust, a condition which investigations to be described later will show has a decided effect upon the character of the mixture.

The streets on which the surfaces of 1889 were laid were subjected to very light travel and were fairly satisfactory for that period, but when they were examined in 1894 it was evident that they could have been improved upon by the selection of a better mineral aggregate, containing more filler, and which, consequently, could carry more bitumen.

Of recent years there has been a distinct improvement in the grading of the mixture laid in Washington, as shown by the following analysis of the pavement laid by the Brennan Construction Company on Pennsylvania Avenue in 1907.

PROPORTIONS.

Asphalt cement (Bermudez)	102 lbs.	= 11.5%
Limestone dust	55 "	= 6.2
Sand	731 "	= 82.3
	888 "	=100.0%

ANALYSIS.

Bitumen	10.5%
Sand, passing 100-mesh sieve	25.0
" retained on 100-mesh sieve	10.3
" " " 80 " "	12.4
" " " 60 " "	26.6
" " " 40 " "	23.1
" " " 20 " "	2.6

In some other cities similar conditions are met with in regard to the available materials for making the mineral aggregate, and experience has shown that where the streets to be paved are carefully drained and the traffic is not heavy such a mixture will prove satisfactory, although it is probable that if the standard grading had been employed with a cement which is somewhat softer than that which would be used on a heavy-traffic street the life of the pavement would be somewhat extended.

On the other hand, it is the opinion of certain experts that a coarser mixture is more desirable for streets of light traffic, and that where the surface is not thoroughly rolled out and closed up thereby it is more satisfactory than a finer one. There is a possibility that this may be so if the finer standard mixture is not made with a softer asphalt cement, the experience of the author in 1896, in several western cities where streets were paved having no traffic at all, having shown that standard surface mixture laid with a rather hard cement cracked to a very considerable extent after two years. Where, however, a standard mixture was laid on such streets with a very soft cement, cracking has not taken place under the same conditions. For the reason that finer sands are not available in Washington, or in the belief that a coarser mixture is more desirable, the more recent specifications for asphalt pavements in that city call for a sand of the following grading:

Passing 100-mesh	At least 10%
" 80- and 100-mesh	" " 25%
" 10-, 20-, and 30-mesh	" " 15%

In view of the above facts, where fine sand is not to be procured readily, a modified standard for sand grading and finished mixture has been adopted.

STANDARD GRADING FOR LIGHT TRAFFIC.

	Sand.		Mixture.	
Bitumen.	. . . .		10%	
Passing 200-mesh.	. . . .		10	
" 100- "	11	22%	9	18
" 80- "	11		9	
" 50- "	33		26	
" 40- "	15		12	
" 30- "	13	30	10	24
" 20- "	10		8	
" 10- "	7		6	
	100		100	

A very considerable amount of work which has proved entirely satisfactory in small cities and towns has been done on this basis under the author's supervision. Such mixtures would not, however, be satisfactory in all large cities, except on residence streets, and it is because most of the mixtures of the careless contractor are never more satisfactory in their grading than this that they are not entirely successful in their work where it is subjected to heavy traffic.

Excess of Fine Sand of 100- and 80-Mesh Size.—Where the regular sand supplies contain an excess of 100- and 80-mesh material, and where it is impossible to introduce into the mixture the normal amount of 10-, 20-, and 30-mesh grains at any reasonable cost, a new problem is brought to our attention. Such a situation is complicated by the fact that an excess of 100- and 80-mesh grains may or may not be accompanied by the presence of a large amount of 200-mesh material.

If the 200-mesh material is not present the mineral aggregate can, generally, be treated in much the same way as the standard grading, merely allowing for the fact that the greater surface exposed by the grains of the fine material necessitates the use of a larger percentage of asphalt cement. The resulting mixture may be quite satisfactory and, on the other hand, may possess less stability than it should and be more liable to cracking at low temperatures and to displacement. In other respects it may be preferable to the standard mixture, if sufficient filler is used, owing to the fact that the surface is a closer one than when the coarser particles are present.

It may also be necessary to use sand in which, while the coarser particles are present in nearly normal amount, the distribution of the finer sand, the 80- and 100-mesh grains, may be quite different from that found in the standard grading. Such a condition will necessitate changes in the handling of such a sand, as will appear when the consideration of the amount of bitumen which a mineral aggregate will carry is arrived at, and this may be conveniently taken up at this point.

The standard New York sand without 200-mesh material or filler should contain 17 per cent of grains passing the 100-mesh and 17 per cent passing the 80-mesh screen, resulting in the presence of only 13 per cent of each of these grades in the finished mixture. For the purpose of studying the effect of an alteration of the proportions of these two sands some sands have been made up on an experimental basis and the voids, weight per cubic foot, with and without filler, determined. See results tabulated on page 344.

In the sand, both with and without filler, No. 1, the lack of 100-mesh grains and increase of 80 above the usual proportion causes an increase in the voids over those found in the standard New York grading. An increase in both 80- and 100-mesh grains to 5 and 6 per cent each above the normal, No. 5, reduces the voids decidedly with the plain sand and slightly when filler is present, but with all the other arrangements, while the sands alone may be improved, there are larger voids when the filler is present than in the normal mixture. It seems, therefore, that unequal amounts of 80- and 100-mesh are not desirable, but that perhaps larger amounts of both might be, since the voids, when 45 per cent of the two sands are present instead of 34 per cent, are reduced

WEIGHT PER CUBIC FOOT AND VOIDS IN NEW YORK SAND, WITH VARYING PERCENTAGES OF 100- AND 80-MESH MATERIAL.

	1	2	3	4	5	N. Y. Regular Grading with same Sand.
Passing 100-mesh sieve. .	4%	30%	28%	17%	22%	17%
" 80- " " . .	30	4	17	28	23	17
" 50- " " . .	31	31	26	26	26	30
" 40- " " . .	16	16	13	13	13	13
" 30- " " . .	8	8	7	7	7	10
" 20- " " . .	7	7	6	6	6	8
" 10- " " . .	4	4	3	3	3	5
	100	100	100	100	100	100
Per cent 100-mesh grains.	Low	High	High	Normal	High	Normal
" " 80- " " .	High	Low	Normal	High	High	Normal
Weight per cubic foot with no 200.	108.3	110.0	110.0	111.5	112.5	109.9
Voids.	35.1	34.1	34.1	33.2	32.8	34.2
Weight per cubic foot with 13 per cent dust. .	119.4	119.6	118.9	119.0	121.7	120.4
Voids.	28.5	28.3	28.8	28.7	27.1	27.8

slightly. The presence of so much fine material, however, it is feared, would make the mixture mushy, and in addition it is generally very difficult and expensive to accomplish this, since such material is not always available. More asphalt cement is also necessary to cover the fine grains, which makes the mixture more expensive, without an adequate return.

The effect of such changes in the standard grading upon the percentage of bitumen which the mixture will carry is well illustrated by the analyses of the following mixtures which were turned out in New York under the author's supervisions in 1899. See table on page 345.

It must be added, however, that some of the difference in the percentage of bitumen in these cases may be due to a variation in the shape or surface of the sand grains as well as to the grading, and that similar results might not be obtained with the same grading for sands from other localities.

NEW YORK MIXTURE—PAT PAPERS ALL WELL STAINED.

	Standard Average.	A	B	C	D Av. N. Y. Week Ending
Date	N.Y., '99	2-7-'00	9-20-'99	2-28-'00	8-26-'99
Proportions:					
Sand	....	790	775	765	
Dust	....	85	100	110	
Asphalt cement	....	149	95 (Ber.)	167	
Remarks:					
Per cent of 100-mesh grains	Normal	Low	Normal	High	Normal
" " " 80- " "	Normal	High	Low	Normal	High
Passing 100-mesh sieve	17%	12%	19%	28%	16%
" 80- " "	17	24	9	16	23
" 50- " "	31	37	28	37	38
" 40- " "	16	15	20	12	12
" 30- " "	8	5	12	3	5
" 20- " "	7	4	7	3	4
" 10- " "	4	3	5	1	2
	100	100	100	100	100
Bitumen	10.5%	9.5%	9.5%	11.3%	10.4%
Dust and sand (passing 200 sieve)	13.0	15.5	15.5	14.7	12.1
Sand	76.5	75.0	75.0	74.0	77.5
	100.0	100.0	100.0	100.0	100.0

Effect of 200-Mesh Material.—In the case of sands which contain a very considerable amount of material passing the 200-mesh sieve the conditions will be found to be different from any of those which have been previously discussed. That portion of the sand which will pass a 200-mesh sieve may consist, as has been previously shown in considering pulverized mineral matter for use as a filler, of particles resembling sand and of more impalpable material, which may be considered as true dust or filler. The effect of a large proportion of 200-mesh grains in the sand on the surface mixture will depend largely, therefore, on whether they are sandy or fine enough to act as a filler, and also largely on the character of the sandy grains themselves, that is to say, their shape and surface. If the coarser 200-mesh grains are round a mixture containing any considerable amount of them, especially if the remainder of the sand is largely of 100- and 80-mesh size, will be very mushy and readily displaced. In 1901, in Kansas City, Mo., a mixture was turned out the sand of which contained as much as 14 per cent of sandy grains of 200-mesh size. With 10 per cent of filler the resulting mixture was very mushy and marked badly on the street, although it showed by analysis over 19 per cent of 200-mesh material and consequently might be supposed to be a stable mixture. An increase of the filler to 12 per cent improved the general character of the mixture very much, but it was never satisfactory and the use of this sand was abandoned, although it was at first hoped that such a fine mixture, giving an extremely close surface, might be more satisfactory than the coarser standard mixture.

On the other hand, in Toronto, Ont., and in Rochester, N. Y., where the sands at the same time contained 23 and 20 per cent, respectively, of 200-mesh material, the amount of filler could not be carried beyond 4 per cent, as a larger quantity made both mixtures very bally and impossible to roll and rake on the street. In these cases the 200-mesh material apparently acted in itself largely as a filler. At other points loamy sands have been found the loam in which, when it does not bake into balls on being heated in the sand-drums, proves to be a satisfactory filler.

The character of a 200-mesh material in any sand cannot be determined by the use of sieves, as nothing finer than the 200-mesh sieve is available and this will not differentiate between sand grains of 200-mesh size and the impalpable powder which acts as a filler, but this may be done by elutriating the material by the method described elsewhere. In the sands in use in New York, especially in that from Cow Bay on Long Island, considerable extremely fine material is found, this amounting at times to 10 per cent or more passing a 200-mesh sieve. On separation of this material and elutriation it was found that between 50 and 60 per cent of it would at times be in the nature of a filler and at others not more than 30 per cent. In a case where the proportion of sand and filler were about the same it was found that the mineral aggregate would still carry a very considerable further proportion of filler and that the grading must be regarded as being extended in the fine direction as if there were a possibility of differentiating the material with finer sieves than are available. Such a mineral aggregate would carry between 11 and 12 per cent of bitumen, frequently approaching the latter. As will be seen when considering the grading of a coarse asphaltic concrete, in such a material the percentage of bitumen is much reduced by the addition of the larger particles, and it may, therefore, be assumed that on either side of our standard grading we may place other gradings according to the following scheme. It is, of course, to be understood that with very fine grains a certain amount of fine filler would be present, although theoretically absent, while the same would hold in regard to fine material with coarser mixture.

Sieves.					Stand. Mix.					
Bitumen.....	14	.....	.....	.....	10.5	.....	.....	.....	.....	8.0
600..........	13									
500..........	13	13								
400..........	13	13	13							
300..........	24	13	13	13						
200..........	11	24	13	13	13					
100..........	8	11	24	13	13	13				
80..........	5	8	11	24	13	13	13			
50..........	3	5	8	11	24	13	13	13		
40..........	0	3	5	8	11	24	13	13	13	
30..........	.....	0	3	5	8	11	24	13	13	13
20..........	.....	.....	0	3	5	8	11	24	13	13
10..........	.....	.....	.....	0	3	5	8	11	24	13
5..........	.....	.....	.....	.....	0	3	5	8	11	24
3..........	.....	.....	.....	.....	.....	0	3	5	8	11
2..........	.....	.....	.....	.....	.....	.....	0	3	5	8
1..........	.....	.....	.....	.....	.....	.....	.....	0	3	5
½..........	.....	.....	.....	.....	.....	.....	.....	.....	0	3

The above diagram shows that, theoretically, the standard can be pushed up and down, according to the amount of fine and coarse material which is present, and that at the same time it will be found that the amount of bitumen which the mineral aggregate will carry will change to a marked degree. This may be illustrated by the following mixtures:

	New York, 1904.		Chicago, 1901.		Boston, 1901.		Newark, 1901.	
Bitumen..................	12.0%		11.4%		10.7%		9.6%	
Passing 200-mesh sieve.....	19.0		18.6		14.3		9.4	
" 100- " "	10.0	19	33.0	47	12.0	24	11.0	17
" 80- " "	9.0		14.0		12.0		6.0	
" 50- " "	26.0		18.0		26.0		18.0	
" 40- " "	12.0		2.0		10.0		16.0	
" 30- " "	6.0	12	1.0	3	7.0	15	12.0	30
" 20- " "	4.0		1.0		5.0		9.0	
" 10- " "	2.0		1.0		3.0		9.0	
	100.0		100.0		100.0		100.0	

ASPHALTIC CONCRETES.

	Barber Asphalt Paving Co., New York.		Warren Bros., St. Louis, Mo.	
Bitumen..................	6.2%		3.4%[1]	
Filler....................	7.8		2.9	
Sand.....................	29.0		12.0	
Stone passing ¼″ screen....	18.0	57	4.2	81.7
" " ½″ "	21.0		6.6	
" " 1″ "	18.0		55.6	
" retained on 1″ screen .	....		15.3	
	100.0		100.0	

[1] Coal-tar soluble in CS_2.

It is very evident from the preceding that the grading of a mineral aggregate has a very large bearing on the amount of bitumen that it can carry, and it may be stated as a general rule that:

1. If the sand is finer than the standard, increase the filler and the asphalt cement.

2. If the sand becomes coarse, reduce the filler and the asphalt cement.

3. If the 200-mesh material in the sand is high, determine whether it is sand or a filler. If it is a sand, and cannot be avoided by the use of sand from some other source, and if it acts badly in the mixture, get rid of it if possible by means of blowing it out with a forced draft or suction, or add more filler and more asphalt cement if this is impossible. If a portion of it is of the nature of a filler allow for this in the amount of filler that is

added. If the only available sand contains 200-mesh grains, which make a mushy mixture, remedy this by the addition of more filler if possible. In some cases the 200-mesh sand will give a mushy mixture under all circumstances and in this case every effort should be made to do away with the use of such material, or to remove the defect by mixing it with some other sand supply.

Examples of the percentage of 200-mesh material which is so fine as to act as a filler, since it does not settle in water in 15 seconds, is shown for the sands of various cities in the following table:

ELUTRIATION OF 200-MESH MATERIAL FROM PLATFORM SAND

Test number.	71714	55560	56372
City.	Kansas City, Mo.	Chicago, Ill.	Toronto, Ont.
Material passing 200-mesh. . .	3%	6%	23%
Acting as filler.	17.2%	10.9%	8.6%

Test number.	74814	73176	72355	73420
City.	Ottawa, Ont.	Seattle, Wash.	Buffalo, N. Y.	Long Island City, N. Y.
Material passing 200-mesh. . .	13%	10%	12%	18%
Acting as filler.	27%	46.4%	43.2%	54.3%

Examples of very mushy mixtures have not been infrequent in the West. Some years ago a mixture was turned out in Louisville, Ky., having the following composition:

Bitumen.	11.7%	
Passing 200-mesh.	17.3	
" 100- "	6.0	10
" 80- "	4.0	
" 50- "	39.0	
" 40- "	19.0	
" 30- "	1.0	3
" 20- "	1.0	
" 10- "	1.0	
	100.0	

In this mixture about 10 per cent of dust was being used before it was brought to the attention of the author. On examination it was found that the sand was deficient in 100- and 80-mesh grains and contained from 5 to 7 per cent of loam acting as a filler. The reduction of the dust to 4 per cent changed its character so much that it was no longer mushy. The modified surface has proved entirely satisfactory.

In the early days of the industry much difficulty was met with, as has been mentioned in discussing the nature of sands, in turning out a satisfactory mixture in two western cities where river sands were in use. In both cases this was only overcome by the entire abandonment of the supplies in use and the selection of others. With the old supplies the mineral aggregate would not carry ten per cent of bitumen and the amount varied with different deliveries of sand. In another city the mineral aggregate, while well graded, carried too little bitumen to permit the finished surface from responding to the great contraction, due to sudden drops of temperature, with the result that all the pavements in this city were a mass of cracks. With the selection of other sand supplies this has been overcome, and mixtures having the following composition have been produced:

	City No. 1.		City No. 2,	
	1896.	1904.	1896.	1901.
Bitumen	9.9%	11.3%	9.4%	10.6%
Passing 200-mesh	14.1	15.7	9.6	11.4
" 100- "	9.0	15.0	11.0	11.0
" 80- "	13.0	14.0	18.0	17.0
" 50- "	33.0	27.0	26.0	30.0
" 40- "	11.0	6.0	11.0	10.0
" 30- "	6.0	5.0	9.0	6.0
" 20- "	3.0	4.0	4.0	3.0
" 10- "	1.0	2.0	2.0	1.0
	100.0	100.0	100.0	100.0

Here the difficulty lay in the fact that the sand first in use was composed of grains which had a surface of such a nature that a thick coating of asphalt cement would not adhere to them.

The Amount of Asphalt Cement or Bitumen which a Mineral Aggregate Will Carry.—It has become very evident from what has been said in the preceding pages that the amount of bitumen or asphalt cement in any mixture is very variable, depending upon the grading of the mineral aggregate and upon the peculiar surface of the sand grains. It is a self-evident fact that this amount in any mixture should be sufficient to thickly coat every particle of mineral matter and fill the voids in the sand, if the latter are sufficiently small, in the actual size of the spaces between the grains but not in volume, to permit of doing so without making the resulting asphalt surfaces too susceptible to temperature changes. With too much bitumen the sand grains composing the mineral aggregate are readily displaced among themselves, especially in the absence of a sufficient amount of filler, and the surface is not stable and will mark badly and push out of shape. With too little bitumen the surface cracks, owing to its inability to withstand sudden changes in temperature, and also becomes displaced because it is not a solid mass. Mr. Dow's illustration, which compares an asphalt pavement to a seabeach at different states of the tide, is an excellent one. Beach sand with the voids just filled with water, as the tide goes out, is firm and stable. A horse hardly marks it. When it begins to dry out it is loose and is readily displaced. When it is supersaturated with water it is a quicksand.

The proper amount of bitumen for various mineral aggregates in common use may vary from 9 to over 14 per cent. As examples sands found and in use in Moline, Ill., in 1902, would carry but 8.5 per cent of bitumen, while in Paris, France, and London, England, 11.5 per cent could be used, and in Glasgow, Scotland, and Seattle, Wash., over 12.5 per cent, as shown by the following analyses. See table on page 352.

If a strict interpretation of the instructions is followed and only 10.5 per cent of bitumen is introduced the mixture with such sand will, of course, be unsatisfactory, and such difficulties have been frequently met with owing to lack of judgment on the part of yard foremen and superintendents.

The actual amount to be used in any case must be determined by the pat-paper test described on page 514. This test, however, is deceptive unless the mixture is at a temperature where the asphalt cement is quite liquid. With cold mixtures the test is of no value, while excessively hot ones may stain the paper too freely.

City	Moline	Paris	London	Glasgow	Seattle
Bitumen soluble in CS_2	8.4%	11.2%	11.1%	12.0%	12.3%
Passing 200-mesh sieve	15.6	14.7	15.3	18.0	12.7
" 100- " "	14.0	18.7	12.7	15.0	11.0
" 80- " "	4.0	23.1	20.5	25.0	9.0
" 50- " "	16.0	26.3	33.7	24.0	23.0
" 40- " "	17.0	3.9	3.6	4.0	15.0
" 30- " "	13.0	1.6	1.5	2.0	10.0
" 20- " "	9.0	.4	1.1	0.0	5.0
" 10- " "	3.0	.1	.5	0.0	2.0
	100.0	100.0	100.0	100.0	100.0

Characteristic pat papers are illustrated on the following sheets. The paper, Fig. 6, illustrates a light stain made by a mixture which, although of a proper temperature, is deficient in bitumen. The paper reproduced in Fig. 7 illustrates a medium stain, showing a slight deficiency in bitumen. The paper reproduced in Fig. 8 shows a strong stain produced by a standard mixture carrying a suitable amount of bitumen. The paper reproduced in Fig. 9 represents a heavy stain, pointing to the presence of an excess of bitumen if the temperature of the latter is not abnormally high.

Coarse sands such as are found in abnormal mineral aggregates give a rather different stain. Experience will prove the best means of interpreting the test. It is a very valuable one with Trinidad lake asphalt mixture, but less so with others, as other bitumens are more susceptible to temperature changes.

In making a pat test the appearance of the surface of the hot pat is quite as instructive as that of the stain upon the paper, since if the mixture is unbalanced in any way greasiness is often visible, which should be removed by the adjustment of sand, filler, and bitumen, which can only be accomplished by experiment, the reduction of the amount of filler accomplishing this at one time and increasing it at another.

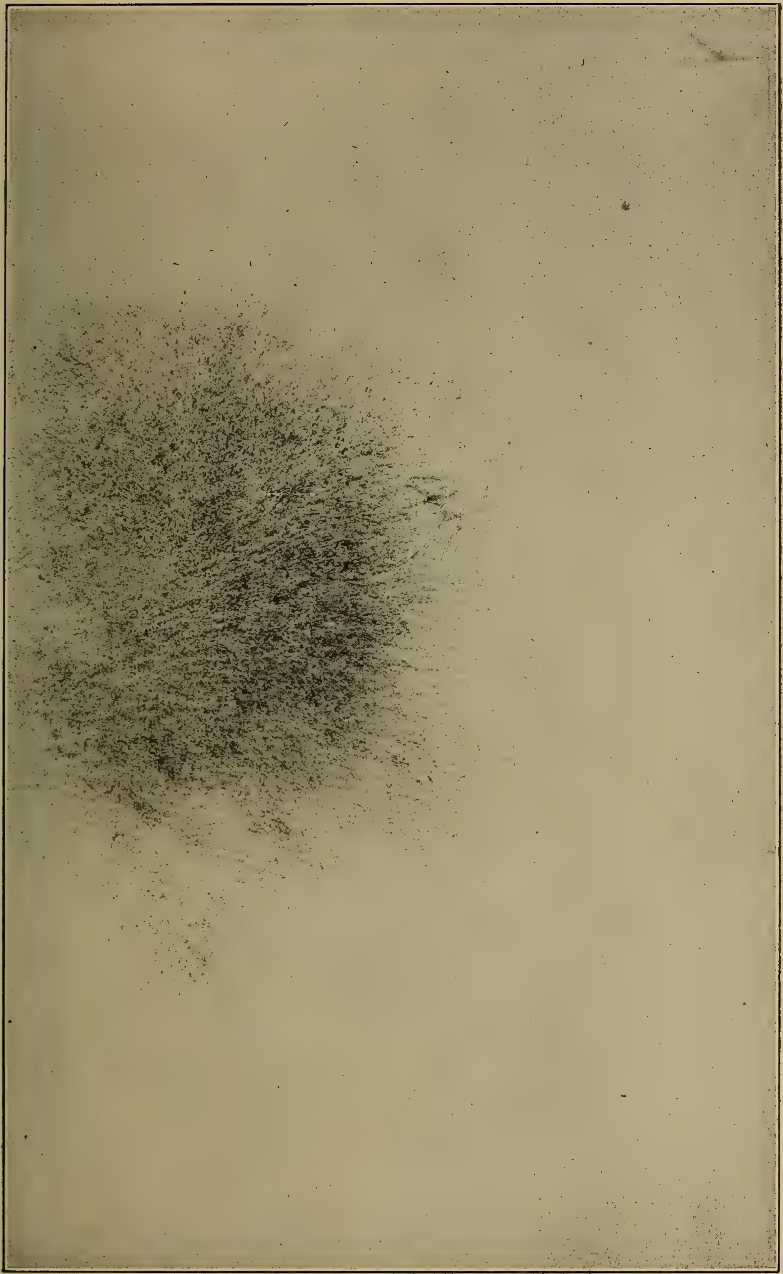

Fig. 6.—Light Stain.

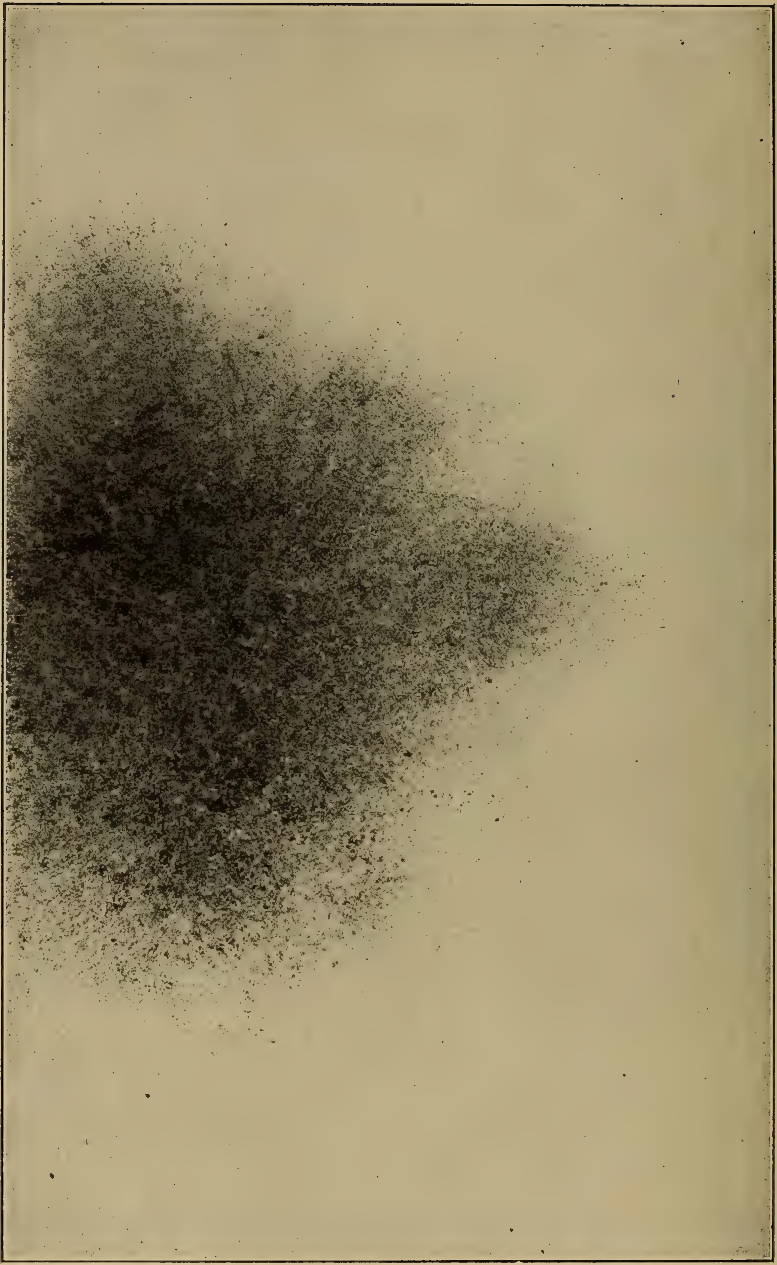

FIG. 7.—Medium Stain.

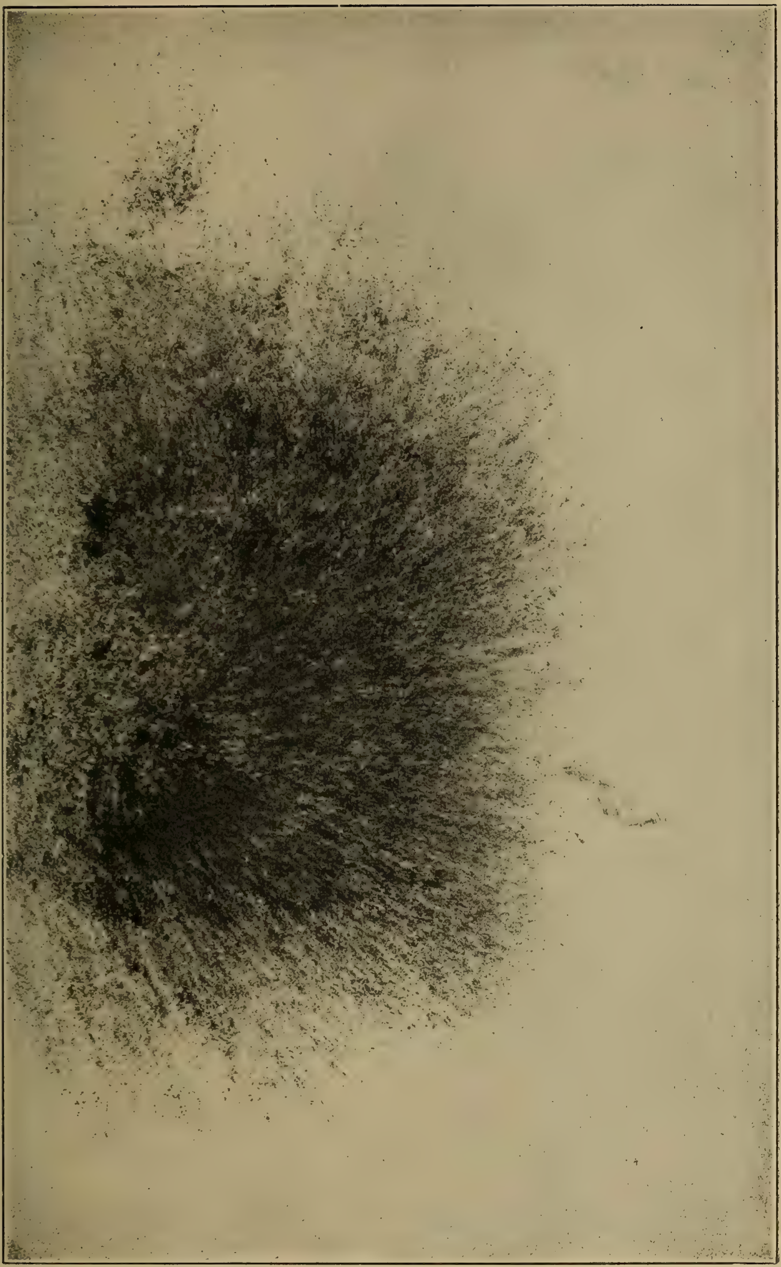

FIG. 8.—Strong Stain.

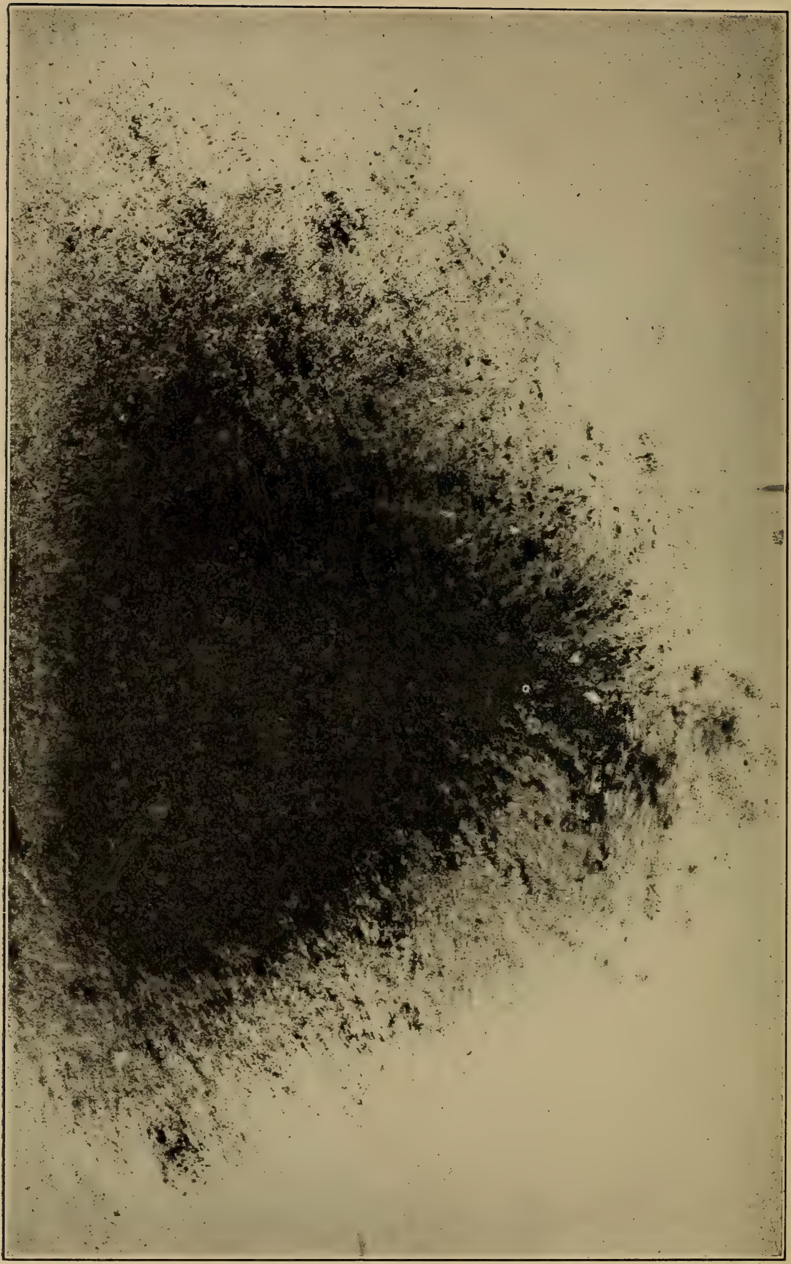

Fig. 9.—Heavy Stain.

Reasons for the Necessity for a Larger Percentage of Bitumen in a Fine than in a Coarse Mixture.—It has already been mentioned that one reason why the finer mixture requires a larger percentage of bitumen than the coarser one is that the extent of surface of the sand grains to be covered with bitumen is much larger in the former than in the latter case.

The number of particles in a gram of grains of uniform diameter and of different sizes and the square centimeters of surface exposed by one gram of such grains are presented in the following tables.

These figures are obtained by means of the following formulas:

$$\frac{a}{\dfrac{\pi(d)^3\omega}{6}}=n$$

and

$$\text{surface}=\pi(d)^2n,$$

where a is the weight of the particles, in this case one gram, d the diameter of the particles, ω the specific gravity of them, and where n is the number of particles.

Where the diameter, d, is given in centimeters and a in grams, the following constants are useful:

LOGARITHMS OF CONSTANTS IN CENTIMETERS.

Mesh Sieve.	Centimeters.	$\log \frac{\pi(d)^3\omega}{6}$.	$\log \pi(d)^2n$.
10	.150	6.6705180	8.8493321
20	.084	6.9150320	8.3457081
30	.058	6.4325281	8.0240055
40	.040	5.9484241	7.7012695
50	.026	5.3871640	7.3270961
80	.020	5.0453441	7.0992095
100	.013	4.4840743	6.7250363
200	.008	3.6515141	6.3033295
1 minute	.005	3.2491541	5.8949895
30 minutes	.0025	2.3360641	5.2930295
2 hours	.00075	0.7674280	4.2472721
16 "	.00025	0.3360641	3.2930295

$$\log\frac{\pi\omega}{6}=.1422441.$$

ONE GRAM OF SAND OF UNIFORM SIZE CONTAINS.

Mesh Sieve.	Millimeter.	Particles.	Square Centimeters.
10	1.50	212.8	15.0
20	.84	1,215.9	27.0
30	.58	3,693.6	39.4
40	.40	11,261.0	56.6
50	.26	41,005.0	87.1
80	.20	90,066.0	113.2
100	.13	328,032.0	174.2
200	.08	1,407,620.0	283.0
1 minute	.05	5,643,700.0	442.4
30 minutes	.025	46,124,900.0	905.7
2 hours	.0075	6,800,990,000.0	1,201.6
16 "	.0025	46,124,900,000.0	9,056.6

1 gram to 1 lb. × 453.59, log. 2.6566654 for particles.
Sq. cm. to sq. ft., divide by 2.9680569 for surface.

Where it is desired to determine the number of particles and the surface exposed by grains of different sizes which go to make up an aggregate of definite weight, the preceding formulas become:

$$\frac{\dfrac{a}{\pi(d)^3\omega}}{6} \div A,$$

where a is the weight of each group of particles and A the total weight of the material, in the following case one pound. Using this, the number of particles and the square feet of surface in one pound of the mineral aggregates in New York mixtures of 1895 and 1898 are found to be as follows. See tables on page 359.

It appears that the finer aggregate presents a surface of 60.5 square feet to the pound, the coarser only 44.4, or 39,407 and 52,093 square feet per 9 cubic foot box respectively; that is to say, the finer has one-third more surface, and as this must be covered, more asphalt will be required for the finer than the coarse aggregate. This explains why the addition of dust will always increase the amount of asphalt cement which a mixture will hold, although the voids may be reduced, as a pound of the best Long Island

NUMBER OF PARTICLES AND THEIR SQUARE FEET OF SURFACE IN ONE POUND OF SAND AND DUST.

NEW YORK MIXTURE, 1895.

Mesh Sieve.	Per Cent.	Particles.	Square Feet of Surface.
10	13	12,592	.958
20	12	66,186	1.579
30	10	167,547	1.901
40	13	664,250	3.593
50	27	5,021,870	11.479
80	10	4,086,220	5.527
100	7	10,415,700	5.952
200	5	31,924,300	6.909
.005 mm.	3	76,671,400	6.480
	100	129,030,065	44.378

One box of mixture (average 888 lbs.), 39,407.664

NEW YORK MIXTURE, 1898.

10	4	3,674	.295
20	7	38,808	.921
30	9	150,796	1.715
40	11	561,866	3.033
50	26	4,835,870	11.054
80	15	6,127,910	8.099
100	15	22,319,400	12.754
200	7	44,694,000	9.672
.005 mm.	6	153,343,000	12.960
	100	232,075,324	60.503

One box of mixture (average 861 lbs.), 52,093.083

City dust with the following siftings will contain the number of particles and the surface in square feet given below:

Size Particles, Centimeters.	Per Cent.	Number of Particles.	Square Feet of Surface.
.008	18.8	120,035,300	25.976
.005	17.7	452,360,200	38.231
.0025	51.3	10,732,950,000	226.825
.00075	5.0	30,775,730,000	58.590
.00025	7.2	150,634,400,000	178.199
	100.0	192,715,475,500	527.821
or if all of the dust is of .0025 cm. in diameter:		20,922,050,000	442.157

This enormous area of surface allows the presence of a larger quantity of bitumen in a fine mixture than in a coarse one. The question of the thickness of the film of the melted asphalt cement on the extended surface of the sand grains is one which, from the elaborate studies of soil physics, it is plain must be of great importance in regulating the amount of bitumen which different sands will require to prevent porosity and instabilty in the mixture. Much pertinent information on this point will be found in Whitney's Bulletins, Weather Bureau, Division of Soils, U. S. Department of Agriculture, and Wiley's Principles of Agricultural Analysis, but our understanding of the question at present is insufficient to permit of going into the matter at this time. It will be investigated in the future.

In this connection some recent determinations by Messrs. Briggs and McCall, of the Bureau of Soils, U. S. Department of Agriculture, " On the Thickness of Adsorbed Aqueous Films," are of interest. They found the following values for several materials:

Silica	167.00×10^{-6}	cm.
Glass	18.00×10^{-6}	"
Quartz	$.45 \times 10^{-6}$	"

The application of these data to an asphalt surface lies in the fact that sand may consist of particles which may vary as largely in the thickness of the film of asphalt which will adhere to them as the materials experimented with above, and this may explain why one sand with the same grading and voids as another may hold different percentages of bitumen.

The New York mixture is desirable in so far as it will usually carry 10.5 to 11.5 per cent of bitumen, when the grains are all coated and the voids filled, as shown by the paper pat test, and this affords a sufficient amount to keep out water and provide for the contraction due to a rapid fall in temperature.

With the low voids it might at first be assumed that such a mixture would hold less asphalt than one with a greater volume, but it has already been shown that the low voids, when accompanied by plenty of fine sand, do not have this effect, as the adsorbed bitumen, or that necessary as a paint coat to cover the more numerous small grains, is something to be considered beyond that necessary to fill the voids. On the contrary, a well-graded fine mixture with small voids will often carry more bitumen than a coarse one with larger voids.

Comparison of the Characteristics of Different Sands Having the Same Sand Grading.—If the sand used in New York, arranged according to the grading in the mixture laid in that city in 1898 and 1899, is to be regarded as most satisfactory, as shown in the following figures, it must be by no means assumed that on that account the New York sand is the best sand; that is to say, consists of the best shaped grains or of those having the best surface to afford a proper adhesion of the asphalt cement and allow of a sufficiently thick coating. As a matter of fact the contrary is the case. It is possible that with other sands accommodated to the New York grading even better results could be obtained than with the New York sands themselves.

	1898.	1899.
Bitumen	10.5%	10.5%
Passing 200-mesh sieve	13.7	13.0
" 100- " "	13.1	12.7
" 80- " "	13.4	12.6
" 50- " "	22.6	23.9
" 40- " "	10.0	12.1
" 30- " "	7.6	6.6
" 20- " "	5.6	5.3
" 10- " "	3.5	3.3
	100.0	100.0

Experiments have been undertaken and completed for determining what the differences are in this respect in the available sands in different cities of the country.

It has been shown that the grading of the New York mineral aggregate is such that the New York mixture is the densest of any satisfactory one in the country, and it appears that in the case of the sand of every other city in the country, when the grading according to which it was used some years ago is changed to that of the New York mineral aggregate of to-day (1899), the density of the resulting mixture is increased with one or two exceptions, and in the same way if the New York aggregate is changed from its own grading to those of other cities its density is decreased.

The grading of the local sands with and without dust, the voids and the weight per cubic foot of each on its own grading, on the grading of the New York sand and aggregate and of the New York sand on the local grading as determined in 1900 are given in the following tables:

GRADING OF SANDS IN AVERAGE MIXTURES IN DIFFERENT CITIES WITH 200-MESH MATERIAL REMOVED—1898 AND 1899.

	Passing Mesh.							Year.
	100	80	50	40	30	20	10	
Philadelphia, Pa..	22	18	30	14	7	5	4	1899
Chicago, Ill.......	21	17	44	10	4	3	1	1898
Kansas City, Mo. .	17	19	37	10	8	5	4	1898
New York, N. Y..	17	17	30	13	10	8	5	1898
Omaha, Neb.	17	16	34	15	8	6	4	1899
St. Louis, Mo	16	14	38	15	7	6	4	1899
Boston, Mass.....	16	12	30	19	10	8	5	1899
Paterson, N. J. . .	15	13	35	17	10	6	4	
Trenton, N. J. ...	11	14	25	14	12	13	11	1898
Washington, D. C.	10	7	23	26	13	11	10	
Louisville, Ky. ...	10	6	50	26	4	2	2	1899
Youngstown, O. .	7	7	23	26	13	11	10	1898

GRADING OF SANDS IN AVERAGE MIXTURES IN DIFFERENT CITIES WITH 13 PER CENT OF 200-MESH DUST.

	Passing Mesh.								Year.
	200	100	80	50	40	30	20	10	
Philadelphia, Pa...	13	15	15	26	11	9	7	4	1898
Chicago, Ill........	13	18	15	38	9	3	3	1	1898
Kansas City, Mo. .	13	15	16	32	9	7	4	4	1898
New York, N. Y . .	13	15	15	26	11	9	7	4	1898
Omaha, Neb......	13	15	14	30	13	7	5	3	1899
St. Louis, Mo.	13	14	12	33	13	6	5	4	1899
Boston, Mass.	13	14	10	26	17	9	7	4	1899
Paterson, N. J. . . .	13	13	11	31	15	9	5	3	1898
Trenton, N. J.	13	10	12	22	12	10	11	10	1898
Washington, D. C..	13	9	6	20	23	11	9	9	1899
Louisville, Ky.....	13	9	5	44	23	3	2	1	1899
Youngstown, O. . .	13	6	16	31	14	13	6	1	1898

WEIGHT PER CUBIC FOOT AND VOIDS IN NEW YORK SAND, WITH NO 200-MESH SAND AND WITH 13 PER CENT DUST, MADE UP ON THE GRADING OF VARIOUS CITIES, COMPARED WITH THE SAND FROM THESE CITIES OF THE SAME GRADING AND WITH THAT OF THE CITIES MADE UP ON THE NEW YORK GRADING.

	Specific Grav-ity.	With no 200.		With 13 Per Cent Dust.	
		Weight per Cubic Foot.	Voids.	Weight per Cubic Foot.	Voids.
New York	2.67	109.6	34.1	118.9	28.5
Omaha, local grading	2.63	113.3	30.9	124.5	24.0
Omaha, N. Y. "		114.1	30.3	126.0	23.1
N. Y., Omaha "		110.0	33.3	121.4	27.2
Trenton, local grading	2.61	111.1	31.6	123.5	24.1
Trenton, N. Y. "		109.0	32.6	118.6	26.9
N. Y., Trenton "		113.7	31.7	125.6	24.5
Kansas City, local grading	2.63	110.4	32.6	122.4	25.3
Kansas City, N. Y. "		111.8	31.8	124.0	24.3
N. Y., Kansas City "		110.3	33.7	121.9	26.7
St. Louis, local grading	2.63	111.9	31.7	122.2	25.4
St. Louis, N. Y. "		113.8	31.9	124.0	25.7
N. Y., St. Louis "		109.7	34.1	121.1	27.1
Paterson, local grading	2.63	110.6	32.6	121.0	26.2
Paterson, N. Y. "		110.0	32.9	122.2	25.4
N. Y., Paterson "		110.6	33.5	121.4	27.1
Buffalo, local grading	2.66	109.6	33.9	120.5	27.3
Buffalo, N. Y. "		111.8	32.4	124.2	25.0
N. Y., Buffalo "		106.8	35.8	118.8	28.6
Chicago, local grading	2.68	109.1	34.6	120.4	27.9
Chicago, N. Y. "		112.5	32.6	123.2	26.2
N. Y., Chicago "		107.8	35.1	119.1	28.1
Philadelphia local grading	2.67	107.8	35.2	119.4	28.2
Philadelphia, N. Y. "		109.6	34.1	121.7	26.8
N. Y., Philadelphia "		110.3	33.7	121.5	27.0
Washington, local grading	2.66	106.1	36.5	119.0	26 8
Washington, N. Y. "		107.2	34.3	117.3	26.2
N. Y., Washington "		112.4	32.4	124.0	25.5
Louisville, local grading	2.62	104.5	36.0	115.7	29.1
Louisville, N. Y. "		107.2	34.3	117.3	28.2
N. Y., Louisville "		108.6	34.7	120.4	27.6

In the preceding determinations of voids in different local sands the sands have been freed from all 200-mesh grains before adding the filler. In practice these sands always contain from 1 per cent of this material in Chicago to 13 per cent in Buffalo. Where so much 200-mesh material not dust is present the full amount of filler cannot always be used. The actual average amount of 200-mesh sand in the supplies of the special cities, which have been examined, and that of the filler used in 1899, with the percentage of the latter passing a 200-mesh sieve, is given in the following table:

AVERAGE PER CENT OF SAND PASSING 200-MESH TAKEN FROM WEEKLY REPORTS; ALSO PER CENT USED IN MIXTURE.

City.	Year.	Average Per Cent Passing 200-Mesh.	Average Per Cent Dust in Mixture.	Per Cent Dust Passing 200-Mesh.	Per Cent 200 Dust Added.	Total 200 Sand and Dust.
New York........	1898	5.0	8.0	95.0	7.6	12.6
Chicago..........	1898	1.0	10.0	85.0	8.5	9.5
St. Louis.........	1899	7.0	5.0	70.0	3.5	10.5
Louisville.........	1899	10.0	8.0	70.0	5.6	15.6
Kansas City......	1898	6.0	10.0	70.0	7.0	13.0
Omaha...........	1899	4.0	8.0	60.0	4.8	8.8
Trenton..........	1898	2.0	7.0			
Paterson.........	1899	6.0	6.0	60.0	3.6	9.6
Youngstown......	1898	1.0	11.0	70.0	7.7	8.7
Washington.......	1899	11.0	8.0	65.0	5.2	16.2
Boston...........	1899	8.0	7.0			
Buffalo...........	1899	13.0	5.0	60.0	3.0	16.0

In Buffalo, with 13 per cent of 200 sand, only 3 per cent of filler can be used, while in Chicago, with only 1 per cent, 8.5 per cent or more is used. The total per cent of 200-mesh sand and dust in many cases is below the amount which should be found in a good mineral aggregate, but it must be remembered that nearly 3 per cent of 200-mesh filler is contributed to the mixture by the fine mineral matter where a Trinidad asphalt cement is in use. Where Bermudez asphalt is the cementing material an additional amount of filler is of course required.

If all these sands are taken and enough dust added to make the total 200-mesh material in the aggregate up to 15 per cent the voids in these aggregates can be determined and the influence of the presence of the 200-mesh sand investigated. This has been done and the results follow:

WEIGHT PER CUBIC FOOT AND VOIDS IN THE AVERAGE SAND OF 1899 FROM VARIOUS CITIES, WITH THE AVERAGE AMOUNT OF 200-MESH SAND AND ENOUGH FILLER ADDED TO BRING IT UP TO 15 PER CENT, PASSING 200-MESH, AND WITH 200-MESH SAND REMOVED AND REPLACED BY FILLER.

City.	Average 200 Sand.	Amount Dust Added.	Weight per Cu Ft.		Voids.	
			Without 200-Mesh Sand.	With 200-Mesh Sand.	Without 200-Mesh Sand.	With 200-Mesh Sand.
New York	5.0	10.0	118.9	120.4	28.5	27.6
Chicago	1.0	14.0	120.4	120.7	27.9	27.7
St. Louis	7.0	8.0	122.2	121.1	25.4	25.8
Louisville	10.0*	5.0	115.7	114.5	29.1	30.0
Kansas City	6.0	9.0	122.4	121.4	25.3	26.0
Omaha	4.0	11.0	124.5	125.3	24.0	23.6
Trenton	2.0	13.0	123.5	125.2	24.1	23.0
Paterson	6.0	9.0	121.0	121.2	26.2	26.0
Washington	11.0†	4.0	119.0	117.4	28.8	28.4
Buffalo	13.0	2.0	120.5	117.0	27.3	29.4
Philadelphia	4.0	11.0	119.5	120.9	28.2	27.3

* Largely fine loam acting as a filler.

† Largely crushed-stone dust acting as a filler.

With only 1 per cent of 200 sand, as in Chicago, little difference is occasioned, but in Buffalo, with 13 per cent of 200 sand, the voids are greater with the sand than with this taken out and substituted by filler. Where the 200-mesh material in the sand is more of the nature of filler than sand there is little difference, but if the 200-mesh material is really sand of the largest size which will pass a 200 sieve the difference is striking. The substitution of such a sand for filler has been made with the sands from the several cities and the results show the effect when compared with those obtained with filler on a previous page:

EFFECT OF SUBSTITUTION OF SAND FOR FILLER.

	13 Per Cent 200-Mesh Sand.	
	Weight per Cubic Foot.	Voids.
New York	115.6	30.5
Omaha, local grading	118.6	27.6
Omaha, N. Y. “	118.9	27.4
N. Y., Omaha “	118.0	29.1
Trenton, local grading	117.1	28.2
Trenton, N. Y. “	114.6	29.5
N. Y., Trenton “	120.0	27.8
Kansas City, local grading	115.0	29.9
Kansas City, N. Y. “	116.8	28.8
N. Y., Kansas City “	117.0	29.7
St. Louis, local grading	116.1	29.1
St. Louis, N. Y. “	117.1	29.9
N. Y., St. Louis “	118.2	28.9
Paterson, local grading	115.6	29.6
Paterson, N. Y. “	116.9	28.6
N. Y., Paterson “	118.2	29.0
Buffalo, local grading	115.9	30.1
Buffalo, N. Y. “	118.4	28.4
N. Y., Buffalo “	114.8	31.0
Chicago, local grading	113.0	32.3
Chicago, N. Y. “	117.6	29.6
N. Y., Chicago “	115.1	30.8
Philadelphia, local grading	113.3	33.1
Philadelphia, N. Y. “	112.7	32.3
N. Y., Philadelphia “	117.0	29.7
Washington, local grading	114.8	31.4
Washington, N. Y. “	112.3	32.8
N. Y., Washington “	120.2	27.8
Louisville, local grading	110.9	32.1
Louisville, N. Y. “	112.8	30.9
N. Y., Louisville “	117.3	29.5

200-mesh sand is generally undesirable because it tends to make the mixture less stable and liable to move, as has already been shown. Our ideal mixture should, therefore, as a rule contain none of this material, and in this respect the New York mixture is at times capable of some improvement, although at others, with quite large amounts, an extremely satisfactory result is obtained.

It is evident from the preceding facts that something besides the mere grading of the sand has large influence on the character of the mineral aggregate and the asphalt surface mixture prepared from it, and this can probably be explained by consideration of the fact that the shape of the sand grains which are of size to pass any given sieve may be so entirely different that they fit together with different degrees of compactness, while the power of adsorption [1] of the surface of the sand grains will have an equal influence. This is not astonishing from what has been observed in regard to the character of various sand supplies when the subject of sand was under consideration.

Further Characteristics Indicative of the Properties of Old and New Asphalt Surfaces.—In addition to the consideration of the preceding characteristics in judging a surface mixture, certain of its physical properties or those of old surfaces, if one of these is under examination, must be determined, such as its density and capacity for absorbing moisture, while others may throw some light on the nature of old surfaces, more especially such as their tensile, crushing, and shearing strength. Old surfaces can also be reheated and the general appearance of the mixture in this condition noted, including the surface of a pat and the stain on a pat paper [2] made, at carefully regulated temperatures, as with a new mixture.

Density.—The density of the best mixtures when thoroughly compacted either by traffic or in the laboratory, as illustrated by that turned out in New York at the present time, should be about 2.22 to 2.25 when made with ordinary limestone and 2.27 when made with Portland cement. The density of such a mixture calculated from that of their constituents is about 2.27 and 2.29, so that in this mixture but a small volume of voids is found. A comparison with these figures of the actual density of old street surfaces which have been examined is therefore of value.

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[1] See page 360.

[2] See pages 353 to 356.

In the old surfaces as they exist in the streets of many cities of the country densities of from 1.89 to 2.26 were found. That on Dodge Street in Omaha had the latter density, and two good surfaces, one from Warwick Boulevard in Kansas City, laid in 1892, and one from Cumming Street in Omaha, laid in 1893, had a density of 2.24. These densities are nearly theoretical, and such surfaces should be able to keep out the water. Howard Street in Omaha, laid in 1895, has a density of only 1.89, and Ohio Street in Chicago, laid in 1894 by the Standard Company, has a density of 2.04. Both of these pavements are cracked, the former very badly. Attempts to compress the latter mixture in the laboratory resulted in obtaining a no greater density.

It is not always the case, however, that a surface of high density does not crack or the reverse. In Omaha, Dodge Street, laid in 1893, has a density of 2.26, but it has cracked probably because the bitumen was too hard. In Chicago, Tripp Avenue, with a density of 2.21, has cracked, as has Walrond Avenue in Kansas City, with 2.24, for the same reason. Baltimore Avenue in Kansas City, of a density of only 2.11, has not cracked, nor has Thirty-ninth Street in Omaha, with a density of 2.10. The extreme densities of the surfaces examined in Chicago, Omaha, and Kansas City were:

	Chicago.	Omaha.	Kansas City.
Good surfaces:			
High density.....	2.20	2.24	2.24
Low "	2.16	2.10	2.11
Medium surfaces:			
High density.....	....	2.26	
Low "	....	2.09	
Cracked surfaces:			
High density.....	2.15	2.21	2.15
Low "	2.04	1.89	2.13

It seemed possible that a low density might be due to lack of compression in surfaces laid in winter. The average density of the summer surfaces as compared with those laid after November first in Kansas City and Chicago seems to confirm this idea, but in Omaha the density is slightly in favor of the one winter surface examined.

	Summer Pavements, Density.	Winter Pavements, Density.
KANSAS CITY, MO.		
Cracked pavements......	2.235 (1) [1]	2.145 (3)
Good "	2.201 (3)	2.136 (2)
CHICAGO, ILL.		
Cracked pavements......	2.155 (5)	2.080 (1)
Good "	2.183 (2)	
OMAHA, NEB.		
Badly cracked pavements.	2.180 (2)	
Medium good "	2.170 (9)	2.182 (1)
Good "	....	2.184 (2)

[1] Number of surfaces examined.

It must be remembered, however, that variations in the relations of bitumen to sand may make a marked difference in the densities, since the greater the percentage of bitumen in a mixture the lower will be its volume weight; that is to say, an excess of bitumen added to an aggregate will lower the density as much as a deficiency. The density of the densest mineral aggregate before the addition of bitumen has been found to be 2.00 in Omaha, the lowest 1.86 in Louisville. It would not be expected, therefore, that a mixture having low voids would have the same gravity in Louisville as in Omaha.

Capacity for Absorbing Water.—Surfaces will absorb water in amount varying with the density and the percentage of bitumen which they contain. With the New York mixture the amount of water absorbed by it in milligrams per square inch and in pounds per square yard when a thoroughly compacted cylinder of the above density is immersed in it for various lengths of time is as follows. See table on page 370.

It appears that more water is absorbed in the first day's immersion than in any subsequent day and that it diminishes in a good mixture as time goes on. When the New York mixture is made with bitumens of different origin the amount of water absorbed

WATER ABSORBED BY CYLINDER OF NEW YORK TRINIDAD LAKE ASPHALT MIXTURE, DENSITY 2.24, WHEN IMMERSED FOR DIFFERENT PERIODS.

Time.	Milligrams per Square Inch.	Total.	Pounds per Square Yard.	Total.
1 day.	.0169	. . . . .	.0480	
2 days.	.0021	.0190	.0060	.0540
7 "	.0092	.0282	.0263	.0803
15 "	.0045	.0327	.0127	.0930
28 "	.0035	.0362	.0101	.1031

will vary. This is illustrated by some data,[1] wherein it is seen that Trinidad asphalt-surface mixtures are quite as impervious as those made with other asphalts and after a lengthy exposure in running water are able to resist impact better than any others.

Comparison of Street Surfaces with New York Mixture.—A comparison of the absorption of water by some of the typical surfaces from old streets in the western cities with that absorbed by the New York mixture will be of interest. See results tabulated on pages 371 and 372.

These results show that the absorption in the old-time, poorly graded surfaces is in inverse proportion to the amount of bitumen they contain and that those of high density, unless they contain enough bitumen to fill the voids, as shown by a paper test, gain more than less dense mixtures with sufficient bitumen.

Such a surface as that on Thirty-ninth Street, Omaha, which the pat paper shows is excessively rich in asphalt cement, excludes water better than the New York mixture, as does the rich Warwick Boulevard surface from Kansas City. The old Howard Street surface with less than 8 per cent of bitumen, of course, absorbs more water than any of the others which were examined. The peculiarities of the other surfaces appear from an inspection of the results in the table. Twenty-sixth Street in Omaha, although it has cracked some, absorbs a comparatively small amount of water, but it must be remembered that water absorption results more in disintegration, scaling, and rotting than in cracking.

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[1] See page 468.

WATER ABSORBED BY CYLINDERS OF OLD SURFACE.

Test No.	Street.	Density of Compacted Cylinder.	Stain on Pat Paper.
	NEW YORK MIXTURE.		
.....	Fifth Ave. mixture	2.24	Heavy
	KANSAS CITY, MO.		
21440	Baltimore Ave.—good	2.240	Heavy
21442	Garfield Ave.—cracked	2.158	Very light
21445	Walrond Ave.—cracked	2.195	Heavy
21446	Warwick Blvd.—good	2.274	Very heavy, coarse
21447	Seventh—good	2.248	Medium
	OMAHA, NEB.		
21448	23d—cracked	2.142	Strong
21456	20th—medium good	2.205	Medium
21461	39th—good	2.209	Very heavy
23253	Cumming—good	2.235	Medium
23251	26th—cracked	2.217	“
23253	Capitol—medium good	2.210	Heavy
23257	Howard—cracked	1.904	None
	CHICAGO, ILL.		
21431	Prairie—good	2.231	Heavy
21433	Tripp—cracked	2.193	Strong
21435	So. Park Ave.—cracked	2.156	Strong
21438	Washington Blvd—good	2.201	Medium

Why the Standard Mixture is Satisfactory.—The standard mixture which has been suggested by the author and which is now universally laid under his supervision where this is possible, on streets of heavy traffic and elsewhere, has been arrived at by the examination of surfaces which have proved successful and not by any theoretical reasoning or experimenting. Practice during the last eleven years has shown that such a mixture is successful. The results of laboratory investigations on the subject have, however, made it possible to explain theoretically and with a good deal of satisfaction why the standard mixture has been a satisfactory one. The greatest factors in the construction

WATER ABSORBED BY CYLINDERS OF OLD SURFACE.

Absorption, Pounds per Square Yard.

Test No.	1 Day.	2 Days.		7 Days.		15 Days.		28 Days.	
		Add.	Total.	Add.	Total.	Add.	Total.	Add.	Total.
New York Mixtures.									
.....	.0480	.0060	.0540	.0263	.0803	.0127	.0930	.0101	.1031
Kansas City, Mo.									
21440	.089	.029	.125	.113	.238	.096	.334	.146	.480
21442	.141	.063	.204	.342	.546	.354	.900	.379	1.279
21445	.095	.080	.175	.231	.406	.357	.763	.580	1.343
21446	.050	.017	.067	.068	.134	.074	.208	.119	.327
21447	.115	.065	.181	.319	.499	.286	.785	.434	1.219
Omaha, Neb.									
21448	.128	.051	.178	.292	.469	.426	.896	.693	1.589
21456	.106	.060	.166	.234	.399	.185	.585	.267	.852
21461	.032	.012	.045	.052	.097	.046	.142	.091	.234
23253	.062	.027	.089	.125	.215	.146	.361	.210	.571
23254	.068	.025	.093	.118	.211	.133	.344	.226	.570
23256	.066	.043	.109	.415	.524				
23257	.273	.103	.376	.531	.907	.767	1.674	.505	2.259
Chicago, Ill.									
21431	.058	.017	.075	.069	.144	.073	.217	.103	.319
21433	.096	.043	.139	.221	.360	.282	.642	.386	1.028
21435	.106	.053	.159	.291	.450	.338	.787	.473	1.253
21438	.089	.037	.126	.208	.334	.241	.575	.309	.884

of a successful asphalt surface is that the mixture shall be so dense as to resist the action of water and impact and at the same time contain sufficient bitumen to permit its responding, without cracking, to a sudden fall in temperature. The standard mixture seems to offer these advantages in a way not supplied by a coarser and more carelessly prepared mixture.

The only way to keep water out of an asphalt surface is to have the voids in the surface mixture as small as possible in size, but not necessarily so in volume, to fill them with bitumen of a consistency which will permit of contraction and to stiffen the latter with a proper amount of filler which will alone permit of the use of a sufficiently soft cement. If the interstitial spaces are few in number but large in size, the asphalt occupying them will be in such large masses, if the voids are entirely filled, that they will easily yield to stress and cause the surface to mark and push and the pavement to appear soft. If the voids are not filled water quickly enters and destroys the pavement. If fine sand is introduced in proper proportions the size of the interstitial spaces is much reduced, the volume of the masses of asphalt filling them is reduced in the same way, and the voids can be thoroughly filled without danger of movement. This is made more certain by the introduction of a filler into the cement, thus stiffening it as it exists between the voids. The function of a filler can be seen by rolling out two cylinders of a cement of the same consistency, one containing 25 per cent of filler and the other none. Their ductility or elongation under stress is then found to be as follows:

AT 78° F.

Without filler—elongation	20.6%
With 25 per cent filler—elongation	34.5

The part played by the filler in an asphalt surface mixture is thus made apparent.

Fine sand of 100- and 80-mesh size is desirable, since it is evident that grains of this size if introduced in the proper proportions among coarser sand grains must reduce the size of the interstitial spaces between the grains even if they do not reduce the volume of the latter. In this way they play an important part in the stability of the pavement, but they play a still more important part in making it possible to use a desirable amount of filler in the mixture. In the early days of the industry, as it was carried on in the city of Washington, it was possible to use only a very small amount of filler in the surface mixture and this never exceeded 3 or 4 per cent. If a larger amount was added, either there or elsewhere, where coarse sands were employed, it was found that when an attempt was made to lay the mixture upon the street it would not rake or spread with ease and was in a condition which was known as "bally." It was impossible, therefore, under such conditions to attempt to close up the surface of the finished pavement by the use of large percentages of filler, although attempts were made to do so. When it was found that the most desirable surfaces contained a considerable percentage of filler not intentionally introduced into them, and that this was accompanied by a similar amount of 100- and 80-mesh sand grains, attempts to duplicate these mixtures with the fine sand present showed that in the presence of the latter much higher percentages of filler could be added without resulting in a "bally" condition of the hot mixture on the street. A consideration of this state of affairs will quickly show that this is due to the fact that in the coarse sand where the size of the spaces between the individual grains were large there was an opportunity for the filler to become balled up with the comparatively large masses of asphalt cement present there, but when the fine sand was introduced this material as it was tossed around in the mixer in a hot condition it broke up these balls and made a smooth and homogeneous mixture which could be raked out on the street with ease. The value of sand of 100- and 80-mesh sizes is, therefore, to be attributed to the two causes mentioned above: one, its reduction of the size of the spaces between the individual sand grains, and, secondly, to the fact that it permits the use of a proper amount of filler in the mixture by preventing the collection of the filler into bally masses.

SUMMARY.

The preceding chapter consists of an elaborate discussion of the theory of asphalt-surface mixtures which does not admit of summarization beyond the statement that the construction of a standard mixture is dependent upon an intimate knowledge of the behavior of sand and the complete mineral aggregate towards the bitumen and of the finished surface mixture towards its environment.

It shows that an asphalt surface to be successful must be so constructed as to resist weathering and impact, which are the two most serious enemies of such a surface, and it also shows how this can be done.

As the surface mixture is one of the most important elements of the pavement the data collected here will be of great interest to the asphalt expert or the person desiring to make himself one, and also to a very considerable extent to the general reader in revealing the amount of skill which is necessary in handling the material which enters into the composition of an asphalt surface.

CHAPTER XVII.

ASPHALTIC OR BITUMINOUS CONCRETE.

The term asphaltic or bituminous concrete has been in use for many years to denote a concrete in which asphalt or some other bituminous substance has been used as a cementing material for a mineral aggregate instead of hydraulic cement. Such a concrete has been employed particularly as a foundation for heavy machinery, the vibration of which it has been desired to do away with where this is a nuisance. Owing to its elasticity and lack of rigidity, it absorbs and does not transmit shock.[1]

As a pavement or roadway bituminous concrete in which coal tar was the cementing material was exploited to a very large extent nearly half a century ago in the United States. Roadways of this description were laid in Washington, D. C. in the early '70's, among them one on Connecticut Avenue by C. E. Evans in 1873, under a contract dated August 7, 1872. This pavement was a failure owing to the character of the cementing material and was resurfaced and covered up with a new one after a short time. It remained in place, however, as a foundation of the roadway, until 1906, when it was removed, on repaving the street, and the construction of a hydraulic concrete foundation. The author was present when the old surface was torn up, and collected specimens of the original Evans concrete as being of interest and

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[1] See Delano, "Twenty Years' Practical Experience of Natural Asphalt and Natural Bitumen," London, E. & F. N. Spon, 1893. Malo, "L'Asphalte. Son Origine, Sa Preparation, Ses Applications," Paris, 1866 and 1898. Letouze et Loyeau, "Traite pratique des Travaux en Asphalte," E. Bernhard et Cie, Paris, 1897.

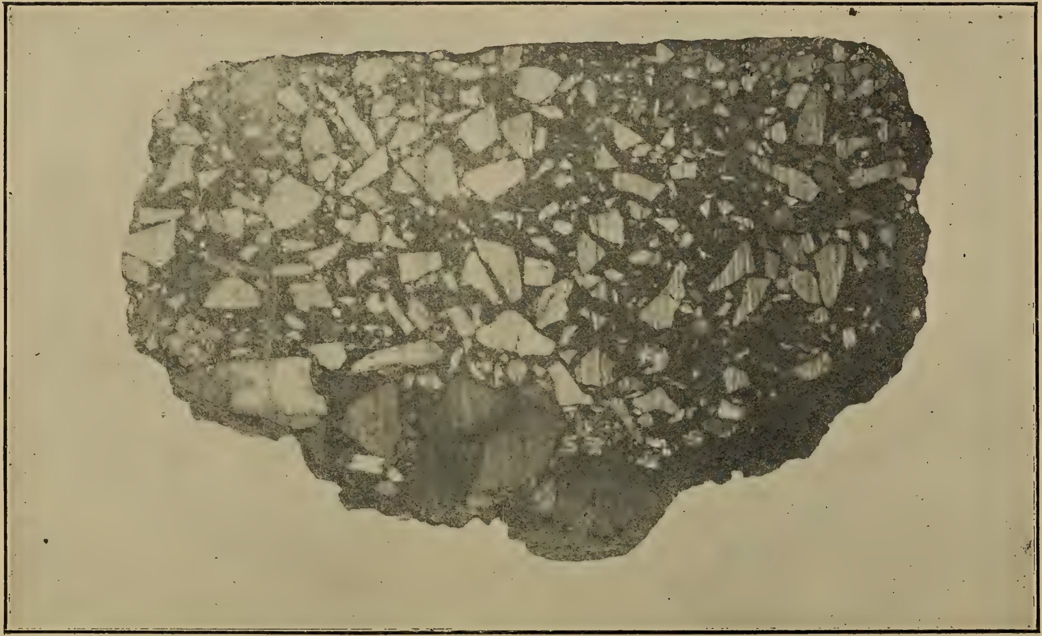

Fig. 10.

as illustrating the earliest bituminous concrete in use as a roadway, which has been preserved. A sawn section of this pavement is shown in Fig. 10. It will be seen that the mineral aggregate in this bituminous concrete consists of broken stone of various sizes, sand and coal tar as a cementing material. This

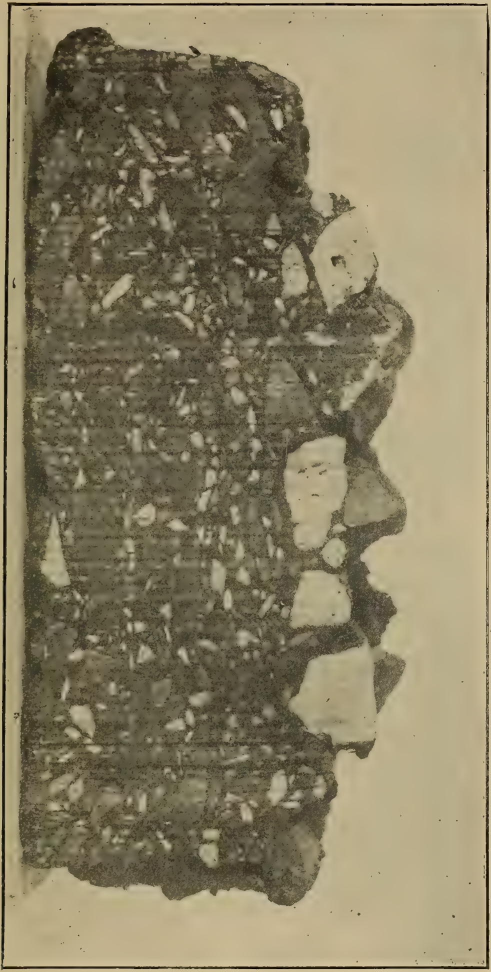

Fig. 11.—Asphaltic Concrete Surface, Muskegon, Mich., 1902.

is more strikingly shown by an analysis of the material which resulted as follows.

EVANS' CONCRETE PAVEMENT, 1873.

	Entire Pavement.		Mineral Aggregate.	
Bituminous matter soluble in CS_2	3.0%			
Mineral matter passing 200-mesh screen	3.2		3.4%	3.4
" " " 10 " "	37.1	37.1	38.2	38.2
" " " 8 " "	2.7		2.8	
" " " ¼ inch "	10.5	13.2	10.8	13.6
" " " ½ " "	14.3		14.7	
" " " ¾ " "	14.7		15.2	
" " " 1 " "	14.5	43.5	14.9	44.8
	100.0		100.0	

Density of concrete	2.73
" " stone	2.86
" " sand	2.65
Voids in mineral aggregate	23.7%

The concrete does not differ in a great degree from similar material which has been used as street roadways within the last few years, at least as far as the grading of the mineral aggregate is concerned, as will appear from analyses which follow. Much of it was laid in Washington at the time mentioned, but all of it was unsatisfactory and required resurfacing within a few years. It is of interest only as showing that a bituminous concrete was recognized as long ago as 1873 as a possible material for paving purposes.

Asphaltic concrete, as far as the author is informed, was first proposed for use as a pavement in 1896. A sidewalk of this material was constructed on West Avenue at Sixth Street, in Long Island City, N. Y., at the plant of the Barber Asphalt Paving Company at that point. The development of the concrete used was the result of some investigations conducted to determine whether a satisfactory material of this description could be assembled from a well graded mineral aggregate and an asphaltic cement which would be suitable for lining a canal. In order to obtain

COAL-TAR CONCRETES, 1902–1906.

	Cleveland, Ohio. 1902	St. Louis, Mo. 1903	St. Louis, Mo. 1904	Toronto, Ont. 1904	Waterbury, Conn. 1905
Soluble in CS_2	3.9%	3.4%	5.0%	5.5%	4.3%
Passing 200 screen	7.1	2.9	5.6	5.0	5.5
" 100 "	18.8	12.0	23.8	26.0	21.9
" $\frac{1}{4}$-inch screen	13.9	4.2	8.2	14.7	6.3
" $\frac{1}{2}$ " "	....	6.6	19.0	17.5	3.6
" $\frac{3}{4}$ " "	....	....	....	16.8	10.8
" 1 " "	56.3	55.6	38.4	8.4	23.3
Retained 1 " "	....	15.3	.0	6.1	24.3
Total	100.0	100.0	100.0	100.0	100.0

	Springfield, Mass. 1905	Cambridge, Mass. 1905	Boston, Mass. 1905	Lynn, Mass. 1905	Port Huron, Mich. 1906
Soluble in CS_2	5.3%	5.3%	4.8%	6.2%*	6.9%
Passing 200 screen	3.3	4.4	4.7	5.5	1.8
" 100 "	29.4	30.9	26.5	19.0	13.7
" $\frac{1}{4}$-inch screen	11.4	15.9	14.4	10.5	13.2
" $\frac{1}{2}$ " "	3.3	21.4	24.0	23.1	10.9
" $\frac{3}{4}$ " "	12.8	15.6	23.0	23.1	5.5
" 1 " "	12.5	6.5	2.6	10.1	4.6
Retained 1 " "	22.0	.0	.0	2.5	43.4
Total	100.0	100.0	100.0	100.0	100.0

* Percentages of components used.

a mineral aggregate with a small percentage of voids, it was recognized that it would be necessary to combine the coarsest stone which was to be used with finer stone to fill the voids in the coarser, and this again with sand and fine mineral matter to further reduce them. The relative proportions were determined by experiments.

In the actual production of this concrete mixture, crushed stone, the largest particles of which would pass a screen with openings three-quarters of an inch in diameter, but containing a considerable amount of quarter inch material, was heated and separated into two sizes, coarse particles and those passing a screen with openings three-eighths inch in size. Sand, such as was ordinarily used in the paving business, was heated separately. Finely ground limestone was used cold. These four components were then mixed while the first three were hot, and to them was added an asphalt cement of proper consistency in the predetermined proportions. The resulting concrete mixture was tamped into a wooden form from which the resulting block was removed on cooling. Its dimensions were 3×4×1 in feet. It was a very successful piece of bituminous concrete, and after exposure to the sun and weather for nine years had preserved its form and showed no signs of deterioration. It was very carefully analyzed in 1905, with the following results:

Test number	81662	
Bitumen	7.9%	
Passing 200-mesh screen	9.3	9.3
" 10 " "	34.7	
" 8 " "	.6	
" ¼-inch screen	6.1	6.7
" ½ " "	31.6	
" 1 " "	9.8	
Retained 1 " "	.0	41.4
	100.0	
Voids in mineral aggregate	15.0%	

This concrete, as appears from the above data, consists of a well graded mineral aggregate, the voids in which amount to only 15% of its volume, cemented together into a resistant mass by an asphalt cement. It was so satisfactory that its application as a surface for pavements at once suggested itself. In order to determine whether it could be used in this way practically, a driveway in a store-house at the plant of the Barber Asphalt Paving Company Long Island City, covering an area of 36 square yards, was laid with such a concrete, the character of which is shown by the following determinations made upon a sample of the surface in 1905, after the roadway had been subjected to the traffic of loaded vans for nine years, with no repairs.

Test number	80951	
Bitumen	6.2%	
Passing 200-mesh screen	5.1	5.1
“ 10 “ “	33.6	
“ 8 “ “	3.1	
“ ¼-inch screen	9.3	12.4
“ ½ “ “	27.0	
“ 1 “ “	15.7	
Retained 1 “ “	.0	42.7
	100.0	
Voids in mineral aggregate	14.1%	

The general similarity between the concrete of the driveway and the block is evident. The latter contains more coarse stone, but the voids in the mineral aggregate are practically the same, 14.1 as compared to 15.0 per cent in the samples examined. The fact that an asphaltic concrete, the basis of which is a mineral aggregate of such compact and dense nature as to contain a very low percentage of voids, could be turned out, in a rational and not an empiric way, on different occasions, and successfully placed in forms and as a roadway was thus demonstrated.

At that time there was no sidewalk in front of the office and laboratory of the Barber Asphalt Paving Company on West Avenue, the building having been only recently completed. In view of the success met in laying the driveway, it was decided to construct this walk of the same material, so that its behavior

Test number	82157	
Bitumen	7.3%	
Passing 200-mesh screen	8.2	8.2
“ 10 “ “	24.2	
“ 8 “ “	1.2	
“ ¼-inch screen	7.9	9.1
“ ½ “ “	30.9	
“ 1 “ “	20.3	
Retained 1 “ “	.0	51.2
	100.0	
Voids in mineral aggregate	15.5%	

might be observed in the open air. The area covered was about 90 square yards, and the surface was supported upon a broken stone and cinder foundation. The character of the mixture laid is shown on the bottom of preceding page, as determined in 1905 from several samples taken from the pavement at that time.

In producing the preceding mixture, the records show that the components were combined in the following proportions:

Stone, passing ¾-inch screen	450 lbs.	=	46.2%
" " ⅜ " "	125 "	=	12.8
Sand, " 10 mesh screen	250 "	=	25.6
Filler, dust, 60% passing 200-mesh-screen	50 "	=	5.1
Asphalt cement	100 "	=	10.3
	975		100.0

The mineral aggregate, it will be seen, as has already been mentioned, was made up of two sizes of stone, of sand, and a filler in the shape of a fine mineral dust. They were combined in such proportions as to make a very dense aggregate having voids, varying on account of some segregation in laying the material, of from 13 to 17 per cent, and averaging 15.5 per cent. This aggregate was assembled on the previously well established principle that to accomplish the desired result—a dense concrete—the voids in the coarsest stone must be filled with particles of suitably smaller size, and the voids in this combination again with other still smaller ones—in this case sand—and still further with material finer than sand—in this case mineral dust. The actual proportions were worked out by packing the materials solidly in a box holding a cubic foot and determining the percentages of each necessary to obtain the densest aggregate.

The bituminous concrete made in this way has given great satisfaction for eleven years. When a demand arose for such a mixture for roadways, as a novelty, it was very evident that it was only necessary to duplicate the Long Island City mixture of 1896. This was done on a considerable scale in Muskegon, Mich., in 1902, on Muskegon Avenue, under the author's direction. The area covered was 10,736.16 square yards. The mixture had the following composition, as shown by a very careful analysis made of a specimen taken from the street in 1905:

Test number	81117	
Bitumen	7.4%	
Passing 200 mesh screen	7.4	7.4
" 10 " "	34.0	
" 8 " "	2.8	
" ¼-inch "	11.2	14.0
" ½ " "	18.0	
" 1 " "	19.2	
Retained 1 " "	.0	37.2
	100.0	
Voids in mineral aggregate	16.8%	

A comparison of these data with those for the mixture of 1896 shows the striking resemblance of the two materials, although the Muskegon mixture contained less stone. The pavement was, in fact, a duplication of the Long Island City work. It has proved entirely satisfactory after six years use.

In the following year, 1903, an asphaltic concrete pavement was laid in Owosso, Mich., with a mixture having a similar composition, but containing more coarse stone.

Test number	80904	
Bitumen	7.4%	
Passing 200 mesh-screen	5.2	5.2
" 10 " "	29.4	
" 8 " "	2.2	
" ¼-inch screen	3.5	5.7
" ½ " "	9.8	
" 1 " "	33.5	
Retained 1 " "	9.0	52.3
	100.0	
Voids in mineral aggregate	13.2%	

Similar surfaces have been laid in Scranton, Pa., Paterson, N. J., Newark, N. J., in the Borough of Richmond, New York City, and elsewhere in subsequent years. They have proved satisfactory on streets of light traffic where street car tracks are absent, but, like all pavements, cannot be maintained against rails that are not rigid. They will not withstand heavy traffic, as the coarse particles of stone ravel out under the continuous impact of the horses' hoof and shoe, the commonest cause of deterioration of all forms of street pavement. If, however, the asphaltic con-

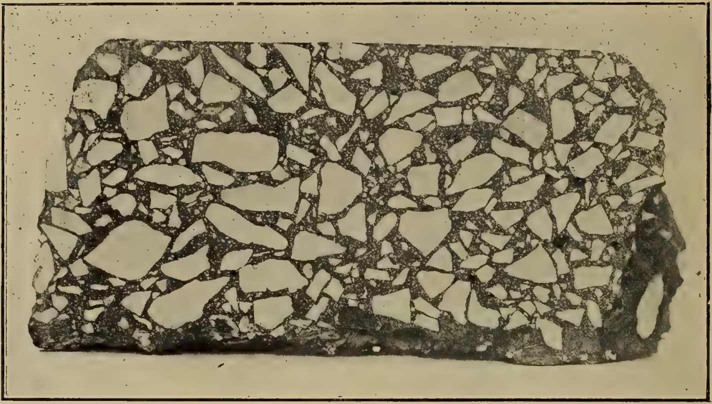

Fig. 12.—Asphaltic Concrete Sidewalk, Long Island City, New York, 1896.

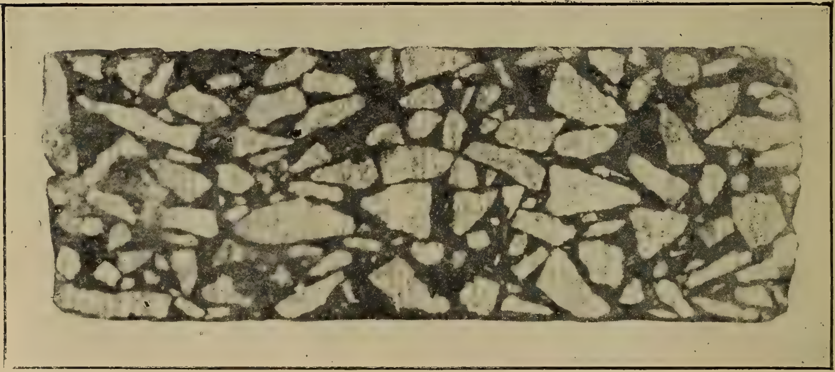

Fig. 13.—Asphaltic Concrete Surface, Broadway, Paterson, N. J., 1906.

crete is covered with an inch of standard surface mixture the resulting pavement has been found to exceed for durability anything that has been hitherto constructed, especially where there is a possiblity of vibration, as along street railway tracks and on a base which is not perfectly rigid. There is every evidence that this form of construction will be the one to be adopted on

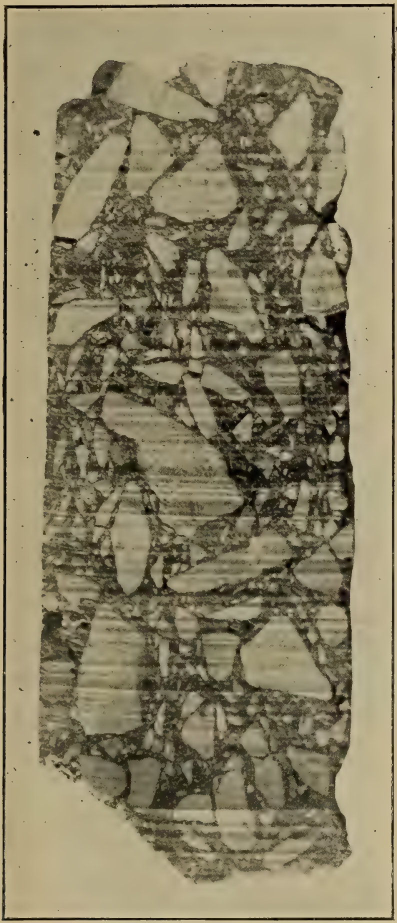
FIG. 14.—Section of Bitulithic Surface, Howard Avenue, New Orleans

streets of heavy traffic in the future, and its use is recommended by the author where trying conditions are to be met. This form of construction is shown in section in Fig. 16.

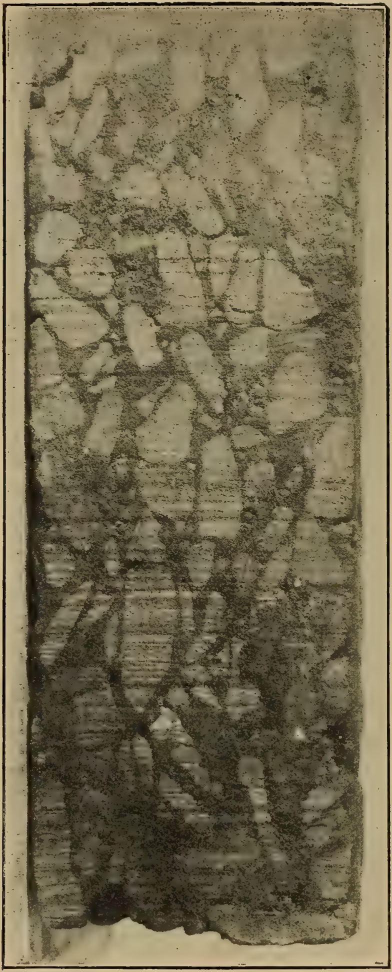

FIG. 15.—Asphaltic Concrete Surface, Broadway, Paterson, N. J., 1906.

Production of Asphaltic Concrete.—Asphaltic concrete can be turned out in any plant which is fitted for the production of the binder and surface mixture for the ordinary form of sheet asphalt pavement, with certain modifications, permitting of the separation of the stone into two sizes after it has been heated in the ordinary heaters provided for binder stone and storage in separate bins. For this purpose the heated stone is passed over a revolving apparatus provided for this purpose. The three materials are then weighed or measured out in the predetermined proportions, screen of sheet metal having perforations $\frac{3}{8}$ inch in diameter. The finer stone which passes the screen is collected in one bin and the coarser into another. There is no necessity for separating them into a greater number of sizes. The sand is heated in the ordinary

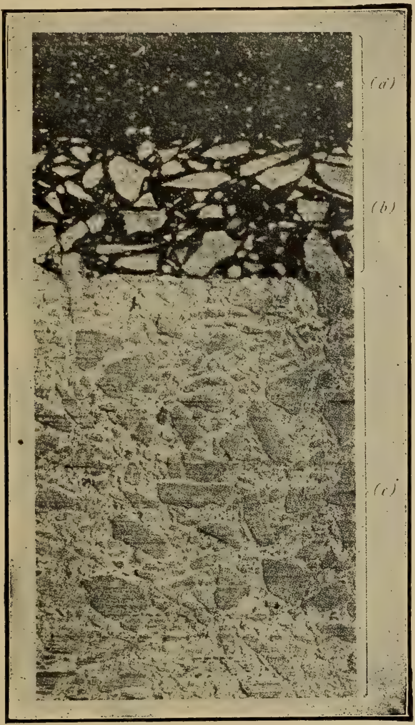

Fig 16.

the dust or filler added, and the combined aggregate thoroughly mixed in the usual pug mill, after which the asphalt cement is added and the mixing continued until the concrete is homogeneous. Portions of the mixture are then compacted under a hot tamper upon a firm surface to determine how satisfactory it is. The hot tamper should bring to the surface of the specimen a slight excess of bitumen, if this is present in correct amount. If the surface remains dry, more asphalt cement must be added, but if it is too greasy, it must be reduced. On cooling the specimen may be broken.

If the concrete is to be used as a binder course, there must be no excess of bitumen and a slight deficiency of sand over that required to fill the voids in the stone, as otherwise the surface will be too readily displaced on such a course under traffic.

The character of the concrete, in either case, can be determined also by its appearance in the truck after the haul from the plant to the street. Where it is to be used as the surface to carry traffic, it should have settled to a compact mass, the top of which should show a slight excess of bitumen as a rich coating, whereas if it is intended for a binder course no excess of bitumen should appear and there should be some evidence of the coarser particles of stone at the top of the load.

In either case, the asphalt cement should be much softer than that in use in the ordinary surface mixture containing sand alone. The penetration should be about 90, as determined by the Bowen penetration machine.

SUMMARY.

An asphaltic concrete pavement is not a novelty. Such pavements have been laid for over twelve years, and have proved satisfactory where not exposed to heavy traffic. On streets like Broadway, in New York, it is unsatisfactory.

CHAPTER XVIII.

ASPHALT BLOCKS.

Pavements composed of blocks of asphaltic concrete in which the coarsest particles of the aggregate are no larger than ¼ or ⅜ inch in size, have been laid for a great many years with considerable success on streets of light or very moderate traffic. The idea of making such blocks originated in a crude way in San Francisco in 1869. The first Board of Commissioners of the District of Columbia stated in its report of 1878 that an experimental piece of pavement of this description had been laid in Washington on E Street, the Board having been influenced to do so by favorable reports of its durability in Providence and Philadelphia. It was not, however, until the application of powerful mechanical presses to the compression of the blocks in 1880 that they proved at all successful. 60,774 square yards of this form of pavement had been laid in Baltimore up to June 30, 1885, and 45,000 had been laid in Washington on a foundation of five inches of bank gravel and a cushion of two inches of sand. The Engineer Commissioner of the latter city reported that the character of the block had much improved in the two preceding years. The blocks were four inches deep, five inches wide and twelve inches long. Many of these pavements are in existence to-day in satisfactory condition, having been subjected only to the most moderate travel on residence streets, and prove the adaptability of such surfaces to similar conditions. The blocks were of sufficient depth to support each other laterally. By June 30, 1889, the area of block pavements in Washington had increased to 117,164 yards, and it had spread to other towns, notably, Baltimore, Md., and Chester, Pa., where 40,000 square yards of block had been laid. This form of pavement made no great further progress until 1896, when the amount reached 200,000 yards, 33,874 of this being in the Borough of Manhattan, and the blocks being 4×4×12 inches in dimension. In 1901 the block as at present laid, 3×5×12, was brought out and laid on East 27th Street from Third to Madison Avenues, since which time large areas of blocks of this description have been put down with varying success, the pavement failing universally under heavy travel and requiring renewal or extensive repairs in from one to two years, and revealing the fact that an asphalt block pavement at least, as at present constructed, is suitable only for residence streets of the lightest travel. The causes of this are not far to seek after a study of the nature of the blocks and of the technology of the industry.

Asphalt blocks consist of a mineral aggregate and a bituminous cementing material, as is the case in the sheet or monolithic asphalt pavement. They differ essentially from the latter form of construction in that the aggregate is much coarser, containing particles as large as ¼ or ⅜ inch in size, while the cementing material is of a much harder consistency, to enable the blocks to be handled in the course of their transfer from the place where they are made to the street and to be stored for some time without losing their shape. Blocks of the ordinary surface mixture which is used in the construction of a sheet asphalt pavement which would withstand the heaviest travel could not be transferred from the plant to the street without doing so, and under a hot summer sun would soon become a monolithic mass in the street, even if it were possible to place them there before they were so much out of shape as to make it impossible to lay them. One of the inherent defects in asphalt blocks, at least as they have been laid up to the present time, is that the cementing material which binds them together is too hard to enable the block to resist heavy travel, and they have gone to pieces, especially in cold and wet weather, after being exposed to it for but short periods of time. In addition, the aggregate of an asphalt block is not a satisfactory one as far as grading is concerned. It consists to-day of crushed trap-rock or similar hard stone, which will pass a screen having openings $\frac{3}{8}$ inch in diameter. Whether these screenings are made particularly for the purpose with steel rolls or are the finer portions of stone which has been crushed for concrete, they always contain an excess of particles of a size which will pass a screen of ten meshes to the linear inch, and be retained on one of twenty meshes. The screening of such material does not vary largely from year to year, as can be seen from the following figures:

Year.	1906			1907		
Passing 200-mesh screen	11	18	13	18	15	20
“ 100 “ “	8	13	6	8	7	10
“ 80 “ “	3	5	2	3	3	4
“ 50 “ “	8	13	8	11	8	11
“ 40 “ “	4	6	3	4	3	4
“ 30 “ “	6	9	7	10	7	10
“ 20 “ “	6	9	9	13	9	12
“ 10 “ “	17	27	24	33	21	29
“ $\frac{1}{4}$-inch mesh screen .	37	......	28	......	27	......
	100	100	100	100	100	100

In 1906 there was a considerably larger percentage of grit than in 1907, but otherwise the grading did not differ essentially. If asphalt blocks are, however, regarded as being composed of small particles of stone or grit, the voids in which are filled with a standard mixture such as had been found most desirable for sheet asphalt surfaces, the portion of the crushed trap-rock which plays the role of sand, it will be seen on calculation, has a grading which is entirely unsuited for the purpose for which it is used, and one which would never be employed in the sheet asphalt industry. There is no way of modifying this grading except by rejecting the excess of 10-mesh material, and even then there remains a deficiency in the grains passing sieves of 80- and 100-meshes, while the expense involved makes it quite impossible to attempt such a modification. The crushed rock must be used just as it comes from the rolls or from the crusher, and the grading is uniformly bad, as can be seen from the analyses of blocks made by various firms and corporations. There would be no possibility of obtaining good service from a sheet asphalt surface with a mineral aggregate of such grading, and it is not surprising, therefore, that asphalt blocks do not wear when subjected to heavy travel, especially as most blocks are made, as has been said, with an asphalt cement, which is far too hard and which, if used in a sheet asphalt pavement, would result in scaling of the surface during damp, cold weather.

The question at once arises as to what opportunities are possible for modifying and improving the character of an asphalt block. As a modification of the grading of the crushed trap-rock is impracticable for economic reasons, if a more satisfactory mineral aggregate is to be obtained, recourse must be had to materials found in nature which can be combined to give the desired grading, such as a well graded sand or clean trap-rock grit of proper size or gravel. There would be no difficulty in obtaining proper sands, such as are used in the sheet asphalt industry, but suitable gravel would be more difficult to find. An opportunity, however, is afforded for improving somewhat the character of the block in another direction, by the use of a more suitable asphalt cement than that which has been in use hitherto, one which is not so susceptible to extremes of temperature. With such a material, a consistency which would be suitable for making a block which would not be so brittle at low temperatures could be used, and, at the same time, the block would not be so soft under a summer sun as to lose its shape on storage without lateral support or under pressure before being placed in the street. Such a cement is found in one prepared from Gilsonite and an asphaltic flux. It can be used of a much softer consistency than one made with Trinidad or Bermudez asphalt without danger of producing a block which will not retain its shape. This can be seen by a comparison of the consistency of the three cements, as they are used in making blocks, at different temperatures.

	Penetration-millimeters.		
	32° F.	77° F.	110° F.
Trinidad asphalt	.2	1.4	6.8
Bermudez asphalt	.2	1.3	7.3
Gilsonite	.5	2.6	7.5

ASPHALT BLOCKS.

Test number	85125	85126	85127	85432	85222	99854
Manufacturer	Interstate	Harlem	Hastings	Washington	Barber Asphalt Pav. Co.	(1907)
Size	3×5×12	3×5×12	3×5×12	4×5×12	3×5×12	3×5×12
Bitumen	6.9%	6.6%	6.0%	7.8%	7.7%	7.7%
Passing 200-mesh	18.9	9.6	15.0	12.8	10.5	15.9
" 100 "	5.3	4.6	6.2	5.6	3.0	7.4
" 80 "	3.2	2.6	3.8	3.4	3.8	4.8
" 50 "	4.0	3.8	6.0	4.5	5.6	6.0
" 40 "	2.8	3.4	4.6	3.0	5.4	5.8
" 30 "	1.8	2.4	4.0	1.9	3.8	4.0
" 20 "	3.4	6.8	7.8	3.4	7.6	6.6
" 10 "	10.7	17.8	17.4	12.0	13.2	15.6
" 8 "	5.5	8.0	7.6	5.0	5.4	7.2
" ¼-inch	29.1	30.4	20.4	29.0	22.8	19.0
" ½ "	8.4	4.0	1.2	11.6	11.2	
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Specific gravity block	2.49	2.61	2.48	2.38	2.53	2.49
" " min. agg.	2.79	2.94	2.85	2.67	2.91	2.95
Voids in mineral aggregate	18.9%	20.6%	22.96%	20.0%	17.4%	23.0%
Penetration of A. C., Bowen	—	—	—	—	35	52
Impact at 40° F. blows	25	34	48	50	34	32
Modulus of rupture at 78° F.	423 521	478 534	815 900	498 442	744 492	500
Rattler, 1800 revolutions, loss	14.3%	6.8%	7.0%	5.9%	7.2%	8.3%

Under any circumstances, asphalt blocks which are suitable to resist heavy traffic will be sufficiently soft to become, in summer, almost a monolothic surface under travel.

The character of asphalt blocks is usually determined both by chemical and physical tests, the latter being the more important and including determinations of density, modulus of rupture, and loss from attrition in a rattler of the type used in testing paving brick. The results of such tests on various blocks produced by the most prominent manufacturers are presented in the accompanying table.

SUMMARY.

Asphalt blocks are very satisfactory under certain circumstances as a form of pavement for residence or light traffic streets, but experience has shown that such a pavement is unable to wear for any length of time under heavy traffic.

CHAPTER XIX.

THE PROCESS OF COMBINING THE CONSTITUENTS INTO A SURFACE MIXTURE.

ASPHALT cement of a desirable nature, a sand or sands which will afford a satisfactory grading, and a sufficiently finely divided mineral matter for a filler being available, it is necessary that these materials should be combined with great care, skill, and uniformity in order to produce a surface mixture which shall be free from criticism.

To bring about this combination some type of plant is necessary which shall make it possible to meet the following conditions:

1. To feed a sand or mixture of sands into the sand heater with great regularity and to have it pass through the drum in such a way that it is uniformly heated and the particles not segregated according to size.

2. To raise the heated sand to a temperature of from 330° to 380° F. as it emerges from the heater, without reducing its temperature essentially, pass it through a sieve which shall remove all particles larger than those passing a laboratory screen of 10 meshes to the inch, and collect it in some form of bin where it can be held for some time without too much radiation and from which it can be drawn without delivering at one time a finer and at another time a coarser material.

3. To have a melting-tank where asphalt cement can be maintained in a melted condition and at a uniform temperature and provided with suitable means of agitation, either air or steam.

4. To have suitable provisions for determining accurately the weight or volume of the constituents entering into the composition of the surface mixture.

5. To have a mixer which shall make an entirely uniform and homogeneous combination of all the constituents which go into it.

6. With a satisfactory plant it is equally necessary to have a foreman to run it who not only understands how to make everything move uniformly but who has had experience in and understands the technology of the industry and the reasons for each step that is taken.

These necessities may now be considered in greater detail.

Sand.—To obtain a sand of satisfactory grading it has already been shown that it is usually necessary to mix two or more sands. To obtain a uniform mixture from sands which will give a proper grading requires care and attention and proper facilities for storing the sand conveniently in the rear of the sand-drums. The two or more sands are then wheeled up or shovelled in separate piles in the neighborhood of the bucket elevators, which are to elevate it to the drums. The sands are then fed into the buckets with a shovel or hoe by laborers in such proportions as may be found by experiment to be necessary. This feeding must be carefully watched, as, owing to the class of labor employed, little dependence can be placed upon the laborer himself. If the feeding is irregular the surface mixture will also be irregular. The regularity of the feeding is determined on the platform by sifting.

To obtain uniformity in the temperature of the sand the type of sand-heater must be a satisfactory one and the firing must be as carefully done as with a steam-boiler. Only experienced firemen should be employed and they should be instructed to watch the temperature of the effluent sand closely.

The hot sand falls from the drums into a boot, from which it is raised to the sand-screen over the sand-bin. This elevator should be well closed in to prevent radiation and the screen and bin should also be enclosed.

The screen should be cylindrical or conical in shape; in the latter case, 3 feet in diameter at one end and 20 inches at the other. It should revolve about 12 revolutions per minute. At the end of the larger diameter it is covered for half of its length with cloth of 10 meshes to the inch, No. 22 wire. The remainder should be 8 meshes of No. 18 wire, the entire length being 5 to 6 feet.

Angle-irons placed lengthwise of the screen at each quadrant will strengthen it and increase its capacity by throwing the sand about.

The sand should not be allowed to fall into the bin irregularly and from whatever point it passes the screen. It should all fall into a hopper which opens over the centre of the bin. This is quite necessary to prevent segregation, as otherwise the fine sand would pass the screen first and go to one side of the bin, the coarser particles collecting at the other.

At best a certain segregation results on drawing sand from the bin. Unless the bin is kept more than half full there is a tendency to form a hollow cone in the centre of the mass of sand, down the sides of which the coarse particles run and accumulate, so that every now and then there is a delivery of coarse and again a delivery of fine sand. This can only be avoided by not drawing the bin down too low.

Various shapes of bin have been suggested, but a cylinder and cone or a half cylinder and half cone are probably the best. The gate should be in the bottom of the cone and not in the side.

Segregation is, however, apt to take place in any form of bin, and that form which prevents this to the greatest extent is the most desirable.

The temperature at which it is necessary to maintain the sand in order to produce a satisfactory mixture will depend on the character of the mixture that is being turned out, the nature of the asphalt in use, the weather, and the distance to the street from the plant. If the mixture is a fine one, carrying much filler and bitumen, if Trinidad asphalt is the cementing material, and if the weather is cool, 385° F. is not too high a temperature for the sand in the bin. If a smaller amount of filler is employed the temperature need not exceed 335°. In any case the mixture should reach the street at such a temperature that it can be raked freely. In the best New York mixtures the temperatures average 330° F. The average mixture of the country will reach the street at 310°. The above applies to a standard Trinidad mixture. If other asphalts are used the temperatures must be considerably reduced, as they will suffer from such heat. The hardening effect of hot sand on asphalt cement has already been noted, and should always be allowed for in those mixtures made with susceptible bitumens such as Bermudez and the hard residues from petroleums or where the flux in use is one carrying much volatile oil.

Melting-tanks.—The melting-tanks in which the asphalt cement is made at the smaller plants or into which it is drawn from the refining-tanks at the larger ones should be so constructed that no portion of their contents shall become readily overheated. The bottoms should be protected from direct flame by a fire-brick arch. Agitation is necessary, not only with such an asphalt as Trinidad, for the purpose of keeping the mineral matter in suspension, but with others as well, to keep the material from too long contact with the sides of the tank, and of even temperature, since convection in melted asphalt results in but a very slow motion of the mass.

Agitation with steam is undoubtedly the best method, as the action of air on all oils at a high temperature is very strong, the result of blowing an asphaltic residuum at a temperature of 350° with air for twenty-four hours being to convert it into a semi-solid buttery mass.

Agitation is also a matter of economy as far as the life of the tanks themselves are concerned, as they will burn out very rapidly if sediment or coke is allowed to collect in them.

In plants where a large amount of work is done some provision in the form of a pneumatic lift should be made for raising the cement to the asphalt bucket, where it is gauged or weighed without the aid of manual labor.

The requisite amount of asphalt should be weighed and not measured and the same may be said of the sand. The same volume of sand may vary very much in weight according to the way it runs into the receptacle.

The type of mixer in use in combining the constituents is, of course, of importance and still more so the way in which it is kept in repair and good order. It is usually constructed to mix a volume of 9 cubic feet at one operation, but as large a volume as 18 can be thoroughly mixed in a properly constructed mill and corresponding economy attained. The mixer should be provided with a liner which can be renewed when worn. It should be provided with a set of teeth made of chilled iron or having steel tips which reach within a quarter of an inch of the lining. The teeth should be set on a shaft the bearings of which can be raised or lowered by the introduction or removal of shims so as to bring the teeth nearer or farther away from the liner. It should have a gate which is tight and will prevent the leaking of either asphalt or sand. In the larger types of mixer the gate is controlled by some power appliance.

The mixer rests on what is technically known as the platform, which is sufficiently elevated to admit a truck beneath. Behind the mixer is the sand-box in which the sand and filler are weighed or measured out. Over it is the bucket for the asphalt cement suspended from a scale. The sand and filler having been weighed in the box and the A. C., the technical designation of the asphalt cement, in the bucket, the two former are allowed to run out through a gate into the covered mixer, which is, of course, in motion, or if the sand-box is one that has no gate, it is dumped into the mixer. It is allowed to remain there for from 15 to 20 seconds to mix the dry materials thoroughly. The asphalt cement is then poured or run directly into the middle of the dry mix and not spread about over different parts of it, as the mixer teeth will bring all the sand to the centre to meet the bitumen, but will not be able to do so as readily with the latter. After the introduction of the asphalt cement the mixing is continued for about one hundred revolutions. The gate to the mixer is then opened and the mixture dropped into the truck.

Where the platform is large enough a testing-room should be provided there for the use of the yard foreman; otherwise it should be upon the ground in front of the mixer, as in the case of a railroad plant. He should have there a set of sand-screens, a sand-balance, a flow outfit for controlling the consistency of his A. C. and manilla paper for making pat tests of his mixture. He should screen samples of sand taken from the boot of the sand-drums and from the bin in order to be sure that the sand mixture is being fed in the proper proportions and evenly. He should make comparative flow tests of the asphalt cement he has in use with that of the standard furnished him for the purpose. Finally, he should make frequent pats of his mixture to determine whether it is carrying a proper amount of A. C. and whether it is properly balanced. These points are recognized by the stain made by the bitumen on the paper and by the appearance of the surface of the hot pat when it is held on a level with the eye. Experience is, of course, required to interpret these latter tests and to understand the indications which are afforded. In addition such samples should be taken on the platform as are needed for examination in the laboratory by more accurate methods.

The Production of Binder.—Binder is turned out in exactly the same way as the surface mixture except that the temperature and not the grading of the stone is to be watched and the mixing is done in a mixer having fewer and shorter teeth. The temperature of the binder can be appreciably lower than that of the surface. It should certainly not be so hot as to cause the asphalt to run off the stone, as in that case it will reach the street without sufficient cementing material to hold it together, a result often noticed in careless work.

Types of Plants and Machinery.—In the preceding pages no mention has been made of any particular type of plant or machinery, as this seemed unnecessary. It is the results obtained and the way in which they are attained which are of the greatest interest to the engineer and to the private individual to whom this book is addressed. One type may do slightly more economical work than another or slightly better. If the latter is true it can be better judged from the character of the material turned out or from the celerity with which the work is accomplished.

It will be of interest here, however, to describe the type of the machinery which the author has found most satisfactory.

Permanent Plants.—In large cities where a very considerable amount of work is done every year a permanent plant will, of course, be established, consisting of proper storage, for two or more grades of sand, in the shape of bins, which can be readily and economically filled from the boats, cars, or other means of transportation which supply the sand. This material should naturally be handled, for economy's sake, as far as possible by power and the bins should be so placed in relation to the sand-heaters that as little labor as possible will be necessary to feed the sand to the heaters.

Sand-heaters.—The sand used in different localities varies from dry bank to dripping-wet river sand, and the heater is required to drive off the moisture and heat to a temperature of 330° F. or over the maximum amount of sand per unit of time with the minimum amount of fuel. As the result of actual trial of many different designs the Iroquois Iron Works has adopted a setting of two horizontal revolving drums, fired with induced draft, as giving the greatest efficiency. By the proportioning of the size of the drum, furnace, and induced draft, all the available heating power is obtained, and by heavy construction and perfection of details the durability of the machine is assured.

The drum-shells are made of $\frac{3}{8}''$ steel plate 20 feet long rolled to a 40″ diameter circle, and are riveted together with two horizontal butt-strap joints. These shells are carried at both ends by heavy cast-iron spiders. Shafts from these spiders extend out beyond the shells and form the journals. The bearing at the hot sand end takes the thrust, being grooved similar to a propeller shaft-bearing. The bearing boxes are fitted with trunnions allowing swinging in a vertical plane. The trunnions rest on swivel brackets, permitting swinging in a horizontal plane; consequently there can be no binding in the boxes, they being able to align themselves at all times, a necessary qualification for a drum revolving in a furnace. Sheet-steel shelves are riveted the entire length of the interior, which give additional heating surface and at the same time are continually lifting the sand and allowing it to fall through the diameter of the drum. The grates are located directly under the cold sand end of the drum-shells.

By means of a fan the combustion gases are drawn along under and back through the drums, coming in contact with the sand, which, by the shelves on the interior of the drums, is distributed through them. By this method the surfaces of the drum are heated by direct radiation from the gases of combustion, and the gases, being drawn through the drum and coming in intimate contact with the particles of sand, not only draw off the released moisture and discharge it outside the setting but also assist in heating the sand to the required temperature. This induced draft is a valuable feature and, as it is easily regulated, increases the capacity and ensures obtaining the maximum calorific value from the fuel. Such a sand-heater is illustrated in Fig. 17.

These drying cylinders are mounted in a brick or steel-plate setting, as desired. For permanent installation the brick setting is preferred. The steel-plate setting is well shown in the illustration, Fig. 17, from which it will be seen that the bearing boxes supporting the cylinders are mounted on a built-up framework at both hot and cold sand ends. This framework consists of a base of riveted channels and steel plate, upon which is mounted cast-iron brackets for carrying the bearing boxes. The sides are made of ¼″ steel plate reinforced with angles. The roof consists of two steel plates. The inner, which is ¼″ thick, is curved to conform to the arc of the drums, thus holding the heat against the latter. The outer covering of medium gauge sheet steel is carried straight across to form a rain-shed. The inner and outer covers are riveted to a trussed angle-iron frame which is absolutely self-supporting. The sides, ends, and roof are made in sections and bolted together, permitting the entire setting to be dismantled into small units which are easily handled and packed for shipment. For the protection of the steel plate it is customary to lay up a lining of one thickness of fire-brick at the sides extending two-thirds the length of the setting. The exhaust-fan is mounted on a timber frame to one side and can discharge into the air or be connected with a dust-collector, as may be preferred.

The drums discharge into a boot, from whence the hot sand is elevated by means of steel buckets on a steel pin chain to a rotary screen covered with cloth of the dimensions which have been described.[1] The screen discharges into a steel storage-bin of from 6 to 9 cubic yards capacity. From the storage-bin it flows by gravity to a triangular-shaped weighing-box mounted on a beam-scale. Here the required amount of stone dust is

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[1] See page 396.

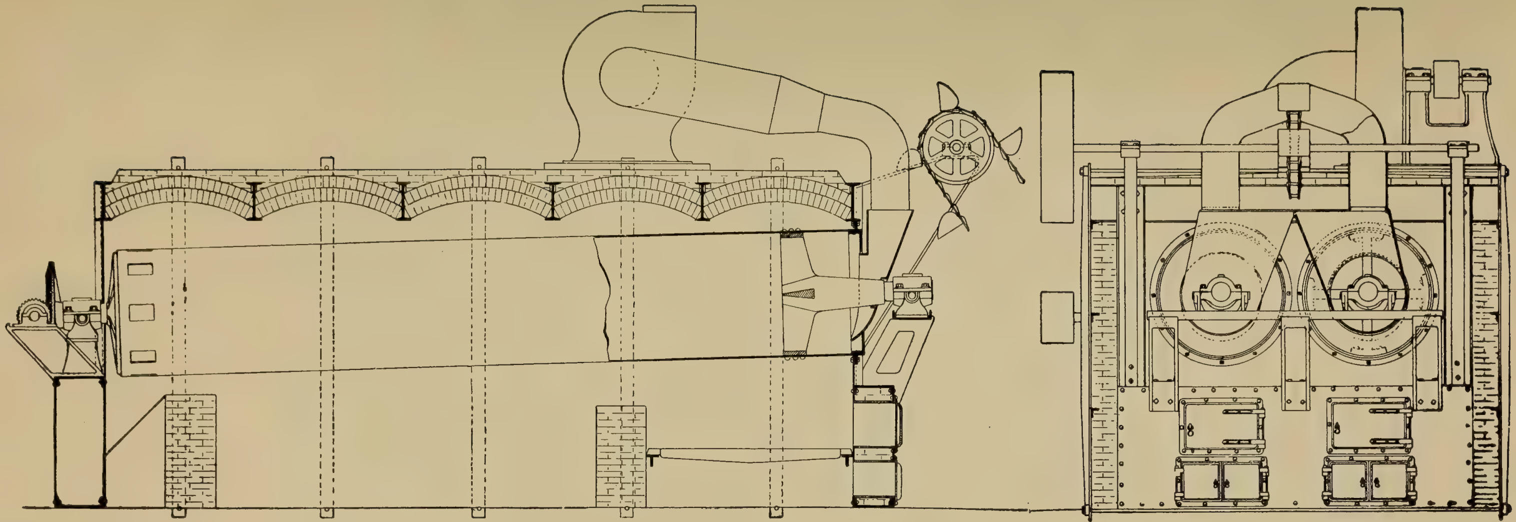

FIG. 17.—Sand-heater, Longitudinal Section.

added and the charge brought up to accurate weight ready for the mixture.

Melting-tanks.—For melting the asphalt two types of kettle are used, fire and steam. The fire melting-tanks are either cylindrical or rectangular, with semicircular bottom, and are set in the furnace with a fire-brick arch between the grates and the bottom of the tank to prevent too rapid heating, which would tend to coke the material on the bottom. The fire melting-tanks are now more generally used for small portable plants in small units of 4 tons capacity. For larger and more permanent plants the steam melting-tanks are preferable.

The steam melting-tanks are rectangular in shape, containing horizontal oval-shaped coils of $1\frac{1}{4}''$ pipe. Fig. 18. One hundred and twenty-five pounds steam pressure is generally used, which gives a temperature in the coil of 345° F. Agitation is accomplished in both fire and steam melting-tanks by horizontal pipes laid at the bottom, with small perforations. To these pipes are deliverd either steam at boiler pressure or air at about 20 pounds pressure. When the asphalt is melted in these kettles it is reduced with the required amount of warm flux, which is measured in a special measuring-tank and flows by gravity to the melting-kettles. The asphalt cement resulting is now ready for the mixer and is delivered to it in one of three ways: In small semi-portable plants a bucket carried by a traveller mounted on wheels on a track is run out from the mixer over the melting-kettles and the cement dipped into the bucket. In many permanent plants the melting-kettles are mounted on a structure sufficiently high for the asphalt cement to flow by gravity directly into the bucket. The third and very largely used method is setting a pneumatic lift just below the bottom of the kettles. This pneumatic lift consists of a steam-jacketed steel cylinder fitted with inlet- and discharge-pipe, air-pipe, and a system of valves whereby the cement flows into the lift from the kettles by gravity, and by the operation of suitable air-valves, air-pressure, which need not be over 5 pounds and is generally the same as the agitation pressure, is admitted on top of the cement, thereby automatically closing the valve in the intake and forcing the

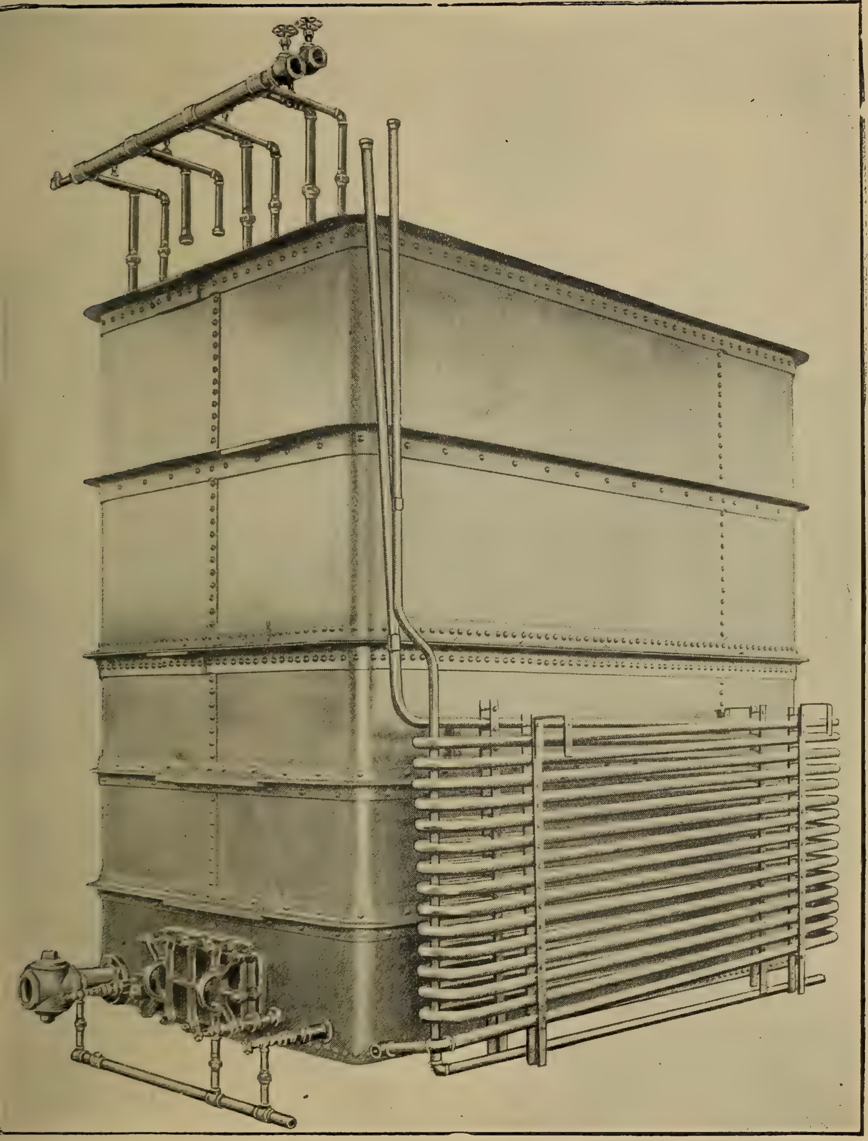

FIG. 18.—Steam Melting Tank.

cement up through the discharge-pipe to the weighing-bucket at the mixer.

Mixer.—The mixer consists of a rectangular-shaped steel shell with semicircular bottom, containing two horizontal square shafts, upon which shafts are bolted blades, or teeth, as they are commonly called. Fig. 20. These shafts are made to revolve by gearing at a speed of from 60 to 75 revolutions. The teeth are made in two different shapes, called right and left hand, and are so set upon the shafts that they work the material horizontally towards the centre, and at the same time are continually tossing it vertically. The result is that an absolutely homogeneous mixture of the sand and asphalt cement is obtained within a minute and a half, when the mixer-man pulls a lever, opening the slide in the bottom, and the finished topping is discharged into the wagon ready for hauling to the street.

Where a plant has but one mixer for turning out both surface mixture and binder it is provided with another shaft for carrying shorter teeth at much wider intervals. This shaft replaces the one used for surface mixture when binder is to be produced.

Portable or Semi-portable Plants.—In cities where work is only done at intervals and where the amount is not sufficiently great to justify the construction of a permanent plant, portable or semi-portable plants are used.

The first type of portable plant consisted of two railroad flat cars, one to carry the boiler and melting tanks and the other for the sand heaters, with the mixing platform between the cars when the plant was set up for use. Such a plant is illustrated in Fig. 21. The cost of setting up and taking down this form of plant when moving from place to place was rather large. The plant has therefore been modified to occupy a single car, rendering the cost of putting it in operation extremely small. A plant of this type, as manufactured by the Iroquois Iron Works, is shown in Fig. 19.

The semi-portable plant is one which is readily taken down and erected, but is not fixed upon a car. It consists of a steel tower with mixer platform, as illustrated in Fig. 22, which is accompanied by the necessary melting-tanks, usually heated by fire. This type of plant has been found very successful in late years and has a large future before it for work in small towns.

Plants of the two previous types require skilled handling and close attention, but with a good foreman and engineer equally good work can be turned out from them as from a permanent plant. and they are highly recommended by the author.

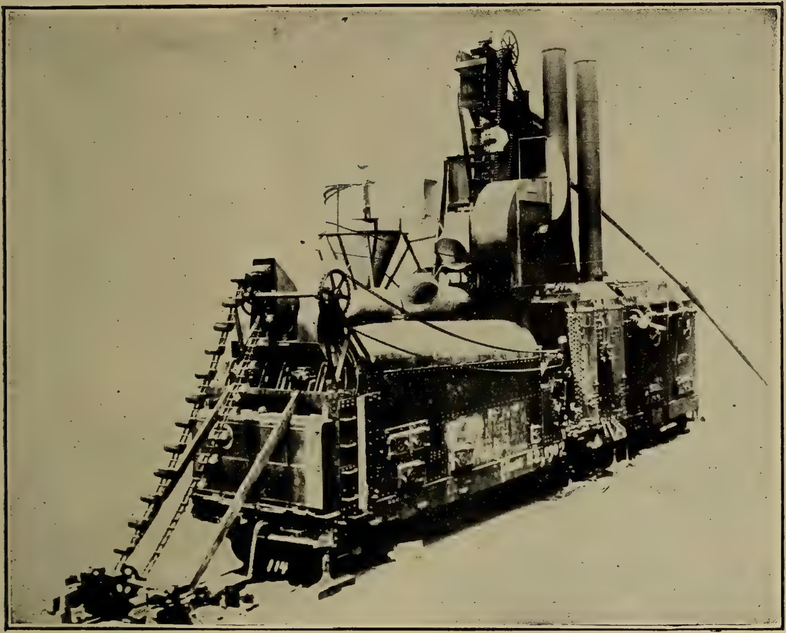

FIG. 19.

Bituminous Concrete Plant.—For the production of bituminous concrete any of the previous types of plant will serve, if the screen over which the heated material passes is arranged so as to separate the heated mineral matter into three sizes, sand, fine stone passing openings $\frac{3}{8}$ inch in diameter, and coarse stone up to $\frac{3}{4}$ inch in size, and if the bin is divided into compartments to hold these separate grades. A special form of plant is not required for this purpose, nor is it necessary to separate the stone into more than three sizes, as has been shown by the successful work done in this way as long ago as 1896.

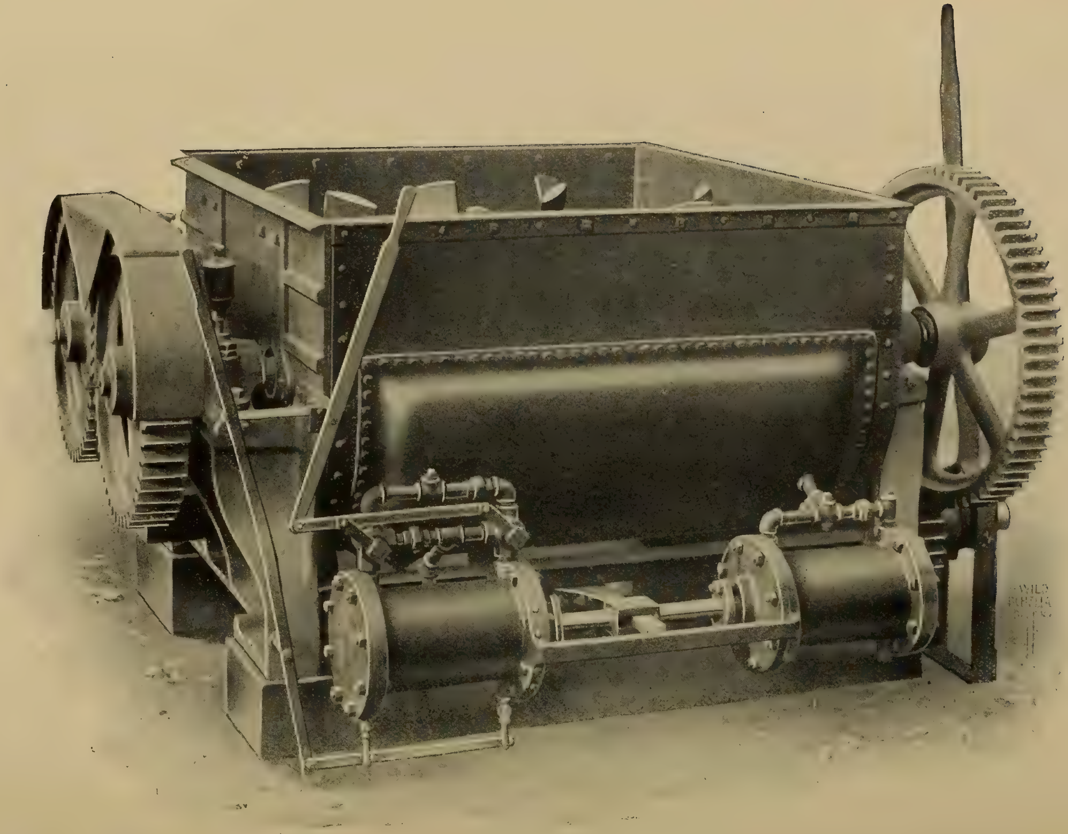

FIG. 20.—Surface Mixer, 15 Cubic Feet Capacity.

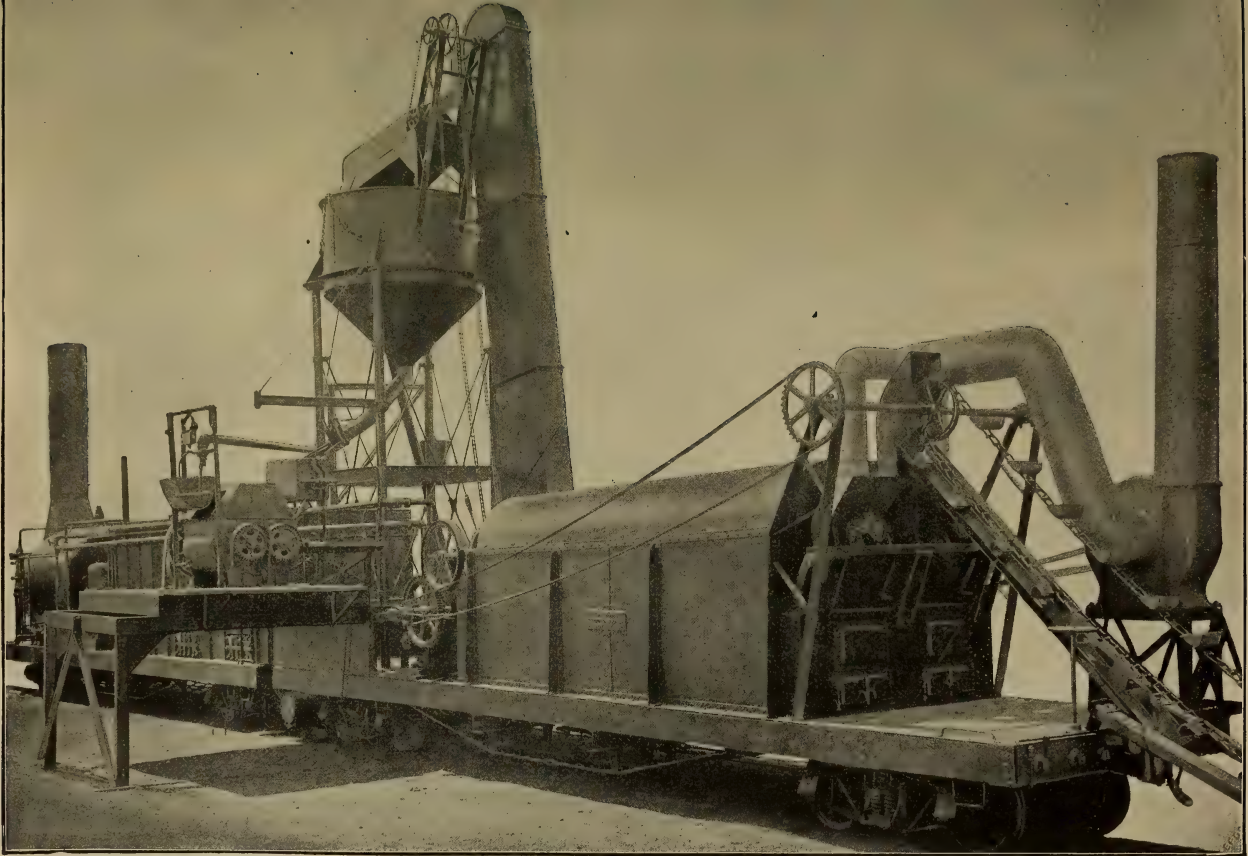

FIG. 21.—Railroad Asphalt Plant.

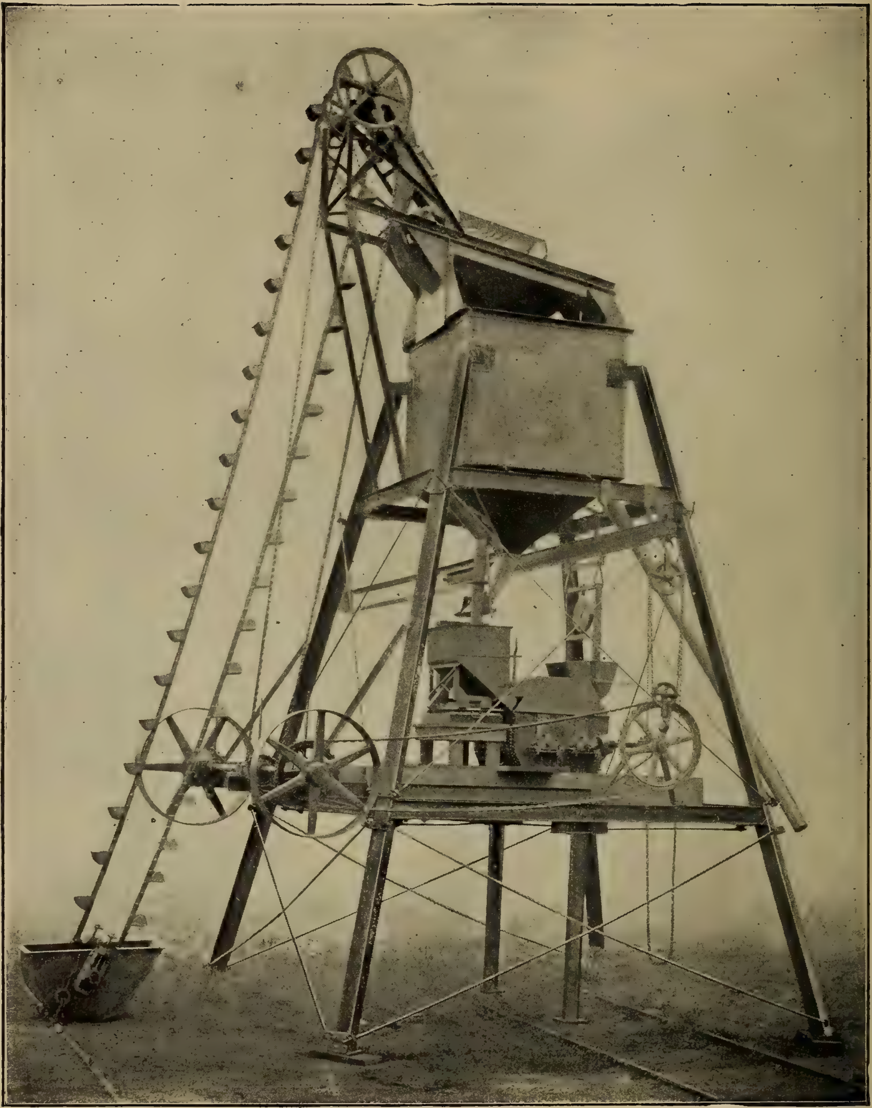

Fig. 22.—Semi-portable Mixing Platform.

SUMMARY.

This chapter describes the process of combining the constituents into a surface mixture, including the machinery and plant necessary for heating the sand and mixing the hot mineral aggregate with asphalt and the type of tanks necessary for melting the latter.

PART V.

HANDLING OF BINDER AND SURFACE MIXTURE ON THE STREET.

CHAPTER XX.

THE STREET.

Transportation of the Materials to the Street.—The transportation of the binder and surface mixture from the plant to the point where the pavement is being constructed is something that cannot be undertaken carelessly and with no other thought than merely getting it there. In the case of the binder the only consideration is that it be so protected that it will not become cold. The condition of the surface mixture when it reaches the street is much more influenced by the conditions to which it has been subjected en route. In the early days of the industry, in Washington, D. C., for instance, the old-fashioned dump-cart, holding from 18 to 27 cubic feet, was in use. Aside from a matter of economy, this is the ideal way to haul the material. Later on, as the size of the mixer was increased in the larger cities, trucks were employed which would hold six batches of 18 cubic feet, or six tons. It was soon found that this method of transportation was unsatisfactory, as the larger mass of surface mixture, during the long hauls which are unavoidable in cities of the size of New York and the constant jarring over rough pavements, became so compacted that it was difficult to break it up after it was dumped on the street, especially if the mixture was a dense one carrying a large percentage of filler and asphalt cement. To offset this disadvantage, however, the larger mass loses heat much less rapidly than is the case with the smaller load, and this is a distinct gain in cold weather and for repair work. A medium course is, therefore, now pursued and loads of about four tons are hauled.

In the smaller cities and towns the question is often a serious one, as the trucks available locally are often not suitable for hauling surface mixture. The worst type is the ordinary dirt truck which dumps by turning over slats which form the bottom of the truck. This truck does not protect the mixture from cooling rapidly, and in dumping the entire mass is so loosened up as to be still further cooled, while much of the material is lost by being carried away on the running-gear.

Whatever the form which the load may take, the surface should be protected from the air, at all seasons of the year, by tarpaulins. The loss in temperature, if the protection is suitable, will not exceed 10° from plant to street in two hours, or often after longer intervals, in warm weather.

It has been found possible to transport large masses of hot surface mixture by rail or by scow for long distances. As an example of this may be cited work done in New Rochelle, N. Y., in 1899. Three hundred tons of mixture were placed on a scow at Long Island City, N. Y., and taken by a tug to the point where the surface was to be laid. Owing to the inclement weather it was impossible to place the material for thirty hours, but the majority of it was in good condition to be laid at that time after the outer cooled portions had been removed. The asphalt pavement laid in this way has been entirely satisfactory.

Construction Work on the Street.—Of the work of construction of an asphalt pavement on the street consideration need be given only to that portion above the base, that of the latter involving no principles which have not already been exploited. In earlier pages the desirable characteristics of a base have been shown, and it is here assumed that the bituminous surface is to be applied to such a base.

The Binder Course.—In general a binder course is the first applied. In the description of the preparation of the binder it appeared that it was sent to the street at a temperature somewhat lower than that of the surface mixture. Arriving there it should be dumped sufficiently distant from the point where the spreading is to be begun or from the point where the previous load ended to permit of turning all the material over without finding it necessary to finally distribute any of the binder over the base at the point where it has been dumped. This is quite necessary, although not as much so as in the case of surface mixture, to permit of spreading the binder course evenly, that portion lying at the point where the load was dumped being considerably compressed by the fall and the weight of the incumbent mass, so that were this not shovelled over the thickness at this point would be greater than elsewhere in the street.

The surface of the load of binder should be bright and glossy, as should the whole mass after it has been dumped. On the other hand, there should be no excess of bitumen, as evidenced by asphalt running from the bottom of the truck or by too great richness of the bottom of the load. Too hot stone may cause the bitumen to run off the binder. One should not be misled by such an occurrence into the belief that the load is too rich. In such a case, however, the surface of the load will generally be dead. Unless the stone is covered with a bright coat of bitumen the binder will have no coherence and should be rejected.

The binder is spread with rakes with long tines. It may be allowed to cool to a very considerable degree before rolling. If rolled too hot it will be much more liable to displacement and to being picked up by the roller. It should be rolled directly with a steam-roller weighing from five to seven tons.

Immediately after rolling it is ready for the application of the surface. If the surface is not applied at once the binder should be protected from becoming soiled by traffic or otherwise. A slight coating of dust will do no harm. The hauling of a sufficient amount of surface mixture over it to cover it should not break it up. If this happens, except on a weak base, it is a sign that it is not of the best quality.

Too often the thickness of binder specified is too small, and in this case it is impossible to lay it so that it will not break up to a certain degree in putting on the surface. An inch of binder is never satisfactory. Binder is composed of stone the larger particles of which are at least an inch in diameter. It is readily seen that no satisfactory bond of such materials can be obtained in such a thickness.

Where an asphaltic concrete course is substituted for an open binder this must be spread with shovels and the back of the rake. The tines should not be used at all, since they have a tendency to pull the larger stones to the surface and cause a segregation of the material.

The Surface Course.—The mixture which is to form the surface should arrive upon the street at a temperature which cannot be defined in degrees of the thermometer. It should be hot enough to work freely under the rake if it has a properly balanced mineral aggregate, but in no case should exceed in temperature one which the particular asphalt cement can resist without being too much hardened, especially in the mixer when being violently agitated with hot sand in contact with air. As different asphalts are very variable in respect to their volatility and stability, the extreme temperature to which mixtures made with them may be heated is quite different. This has already been shown on previous pages. The temperature will also vary with the character of the mineral aggregate. A dense mixture may be heated much hotter without injury than an open one. As a general rule, it may be laid down that some dense Trinidad mixtures, such as that made with a Portland-cement filler, may with safety be raised to a temperature of 340° to 350°, if it is necessary, in cold weather. By this it is not meant that such a temperature is desirable if the mixture can be worked at a lower one, but that no danger will be incurred by its use which is commensurate with the disadvantages arising from inability to handle a cold mixture on the street and consequent poor workmanship.

A Bermudez mixture hardens rapidly at temperatures above 300° and should not be heated above that point unless provision is made for the resulting hardening by making the asphalt cement about ten points too soft. The same may be said of those asphalts which resemble Bermudez, Mexican, western Venezuelan, and the like. The best oil asphalts will resist high temperatures well, but mixtures made with them do not require to be very hot, as bitumen of this character is so liquid at a comparatively low heat that no difficulty is experienced in working them, even the densest, at 280°.

As a general rule, it may be laid down that the following temperatures may be considered normal on the street:

Trinidad asphalt:	
Dense mixture	325° F. to 340° F.
Average “	300° F. “ 325° F.
Open “	280° F. “ 300° F.
Bermudez asphalt:	
All mixtures	280° F. “ 300° F.

The lowest temperature at which a mixture may reach the street and still be considered satisfactory is that at which it may be raked to a proper grade without too much difficulty.

The character of a mixture can be judged, to a very considerable degree, by the appearance of its surface in the truck as it comes upon the street, if the haul has extended for any distance, and by its cohesion when it is dumped. The best mixture, carrying plenty of filler, should have, before dumping, a nearly level and rather bright surface. If the material stands up in a heap as it was dropped from the mixer it is not rich enough. If it tumbles to pieces on dumping, it does not contain enough filler. The best mixtures, which are the only ones suitable for heavy-traffic streets, should stand up and show in part the shape of the truck from which they have been dumped.

This applies, however, only to the natural asphalts. The residual asphalts from asphaltic petroleums become so liquid at temperatures at which surface mixtures are handled that the latter are quite sloppy.

A load of surface mixture, for the same reasons as in the case of binder, only more emphatically so, should be dumped upon the binder so far from the material previously raked out that it will be possible and necessary to shovel it all over in order to get it in place. This is most important, and care in this direction is often lacking. If the mixture at the point where the load is dumped is not shovelled over, but merely brought to grade before rolling, there will be an excess of mixture at that point which will not compress as much under the steam-roller as the neighboring surface, with the result that after the street has been subjected to traffic for some time that part is higher than the rest.

The surface mixture is distributed with hot shovels from the point where it has been dumped to the place where it is to be raked out to the proper thickness for compression. This operation should not be conducted too rapidly. No more should be spread than the rakers can handle. If it is spread too rapidly the rakers will find it necessary to step in it in correcting inequalities of grade, thus compressing the part where their feet fall. This depression they afterward fill with more mixture and therefore leave at that point more than there should be. After the street is opened for traffic this part of the surface does not yield as much to final compression as the remainder and the result is an uneven and bumpy grade which is accentuated with the lapse of time and aids in the disintegration of the pavement from the blows of wheels bounding from the elevated spot to the adjoining surface. Rakers should on no account be allowed to place their feet on the uncompressed surface mixture. If absolute necessity arise the depression should not be refilled.

The mixture after it is spread should be thoroughly raked out with rakes having long and strong tines which will penetrate through its entire depth. It is necessary, in order to obtain a regular surface to the finished street, that all the hot mixture shall be broken up to a uniform state of looseness. None of the material in the state of compression which it has acquired in the truck during the haul to the street should be allowed to remain in lumpy form. If lumps remain in the loose hot material the effect will be the same as that occurring at the points where the rakers place their feet. It is insufficient that the actual surface of the loose hot mixture should represent a uniform thickness; it must also be of uniform consistency all the way through.

The lack of perfect form in asphalt surfaces is oftener due to this cause than any other, but it is, of course, much emphasized on streets of heavy travel where traffic depresses that part containing the least material. With coarse mixtures, and those deficient in filler, which do not become so much compressed in the trucks, and with mixtures poor in bitumen, results such as have been described are not so apt to occur or are brought out less under lighter traffic, and, as a matter of fact, with such mixtures it is possible to give a street surface a much prettier original finish than can often be obtained with standard mixture which carries a high percentage of fine sand, filler and bitumen.

The raking of the material to a proper grade requires a good eye on the part of the workman and proper supervision and a better eye for such work on the part of the foreman. Constant attention and great care are, however, the great desiderata. It is not difficult to make a good raker out of an inexperienced man if he is under good supervision. The great difficulty with all rakers is to make them pull out all their material to a loose condition, especially with a dense mixture such as it is necessary to lay on heavily travelled streets.

The hot mixture having been raked to grade, it was the custom, in the early days of the industry when the mixture was more loose and open and carried less filler and asphalt cement and consequently had less density, to give it its first compression with a hand-roller of comparatively light weight. This may be advisable even to-day with similar mixtures. As a rule, however, the modern mixture has sufficient density to permit the use of a steam-roller at once, and this is the general custom in good practice. The hot mixture is, however, allowed to cool to a point where it will not be displaced or picked up. To avoid the latter difficulty it may be necessary with some mixtures to oil the roller with a mixture of kerosene and water, and it is generally found to be preferable to run the lighter or guide rolls of the roller on the surface first. After the preliminary compression the surface is sprinkled with any fine mineral matter which will give it a color pleasing to the eye. It is not necessary that this should be a hydraulic cement. The excess of dust having been swept off, the surface is allowed to cool still further until the roller can go on and shape it up without displacing it. Experience can alone determine what length of time to allow for cooling. In winter it cannot be long, since if a hardened crust is allowed to form by the chilling of that portion of the mixture exposed to the air, this will have a tendency to break up on further rolling, and fail to make a bond with the main mass, resulting in subsequent scaling.

The aspect of the finished pavement, especially after it has been subjected to traffic for a year or two, will depend as much on the way it was rolled as on the way the mixture has been raked out. The management of a steam-roller requires experience, skill, and judgment. The roller if not run with great regularity and stopped with care at the end of a run will readily displace the surface so that it cannot be easily brought back into form again. The first rolling should be with the length of the street. It should then be rolled diagonally where this is possible as soon as it is evident to the roller engineer that nothing is being accomplished in the original direction. No rule can be laid down as to the length of time necessary for rolling a given area of surface. The time will depend very much on the season of the year and more on the character of the mixture. The hot surface mixture will cool more rapidly in the autumn, and cannot be rolled for the same length of time as in summer, or at least with any effect. Mushy mixtures, where the local sands make mixtures of this description, should not be rolled too much. This would injure them by breaking the bond in the cool mixture. Mixtures on a weak base cannot be rolled to the same extent as those on one that is firm. Certain mixtures which are readily displaced may require a final shaping up with a roller of wider tread than that used for the original compression, one of ten or eleven tons weight and tread. This is by no means always necessary if the roller engineer is skilful and the mixture a good one; although the weight per inch tread is greater in one case than in the other. Following are some determinations of the pressure per inch run for various rollers. See table on page 420.

All rollers are not equally suited for the work. Some are strikingly defective in that they are not well balanced. The side carrying the motive power is much heavier than the other, and the result is that the roller sways, especially when it meets an elevation or depression, thus producing a wavy surface. The

ROLLERS—PRESSURE PER INCH RUN.

IROQUOIS IRON WORKS.

Size of roller	2½ tons	5 tons	8 tons	13 tons
Duplex engine	4×5	6×6	7×7	8×10
Main roll, width of tire	30 ins.	38 ins.	48 ins.	60 ins.
Pressure per linear inch	125 lbs.	210 lbs.	250 lbs.	300 lbs.

best type of modern roller has a compensating weight attached to the channel iron on the side opposite to that carrying the motive power. Whether a roller is properly balanced or not can be determined by running it on a scantling so that the latter is exactly in the middle of the rolls and then noting whether it has a tendency to tip toward the side carrying the motive power. If it does it should be balanced by bolting a weight to the channel iron on the side which is too light.

Rollers should be provided with a steering-gear which can be controlled by power, thus enabling the engineer to give his undivided attention to the street. Such rollers are available. Throttle-valves should be of a kind which permit the gradual reduction of speed.

The importance of having a perfect roller, if good work is to be done, should not be overlooked. That offered by the Iroquois Iron Works, Buffalo, N. Y., is the best balanced and most carefully constructed roller with which the author is acquainted. It is illustrated in Fig. 23.

These rollers are made of various sizes, 2½, 5, 8, and 13 tons, the latter being used for rolling the base and for finally shaping the asphalt surface where mixture requires it after previous compression with a lighter roller. Such shaping is only necessary when the mixture is of a mushy nature and consequently somewhat displaced by the roller of narrower tread.

Work Under Particular Condition.—In the preceding paragraphs consideration has been given only to what may be called straight work; that is to say, the laying of an extended area where everything connected with the work goes on in a perfectly normal way. This, however, is not the only kind that is met. There

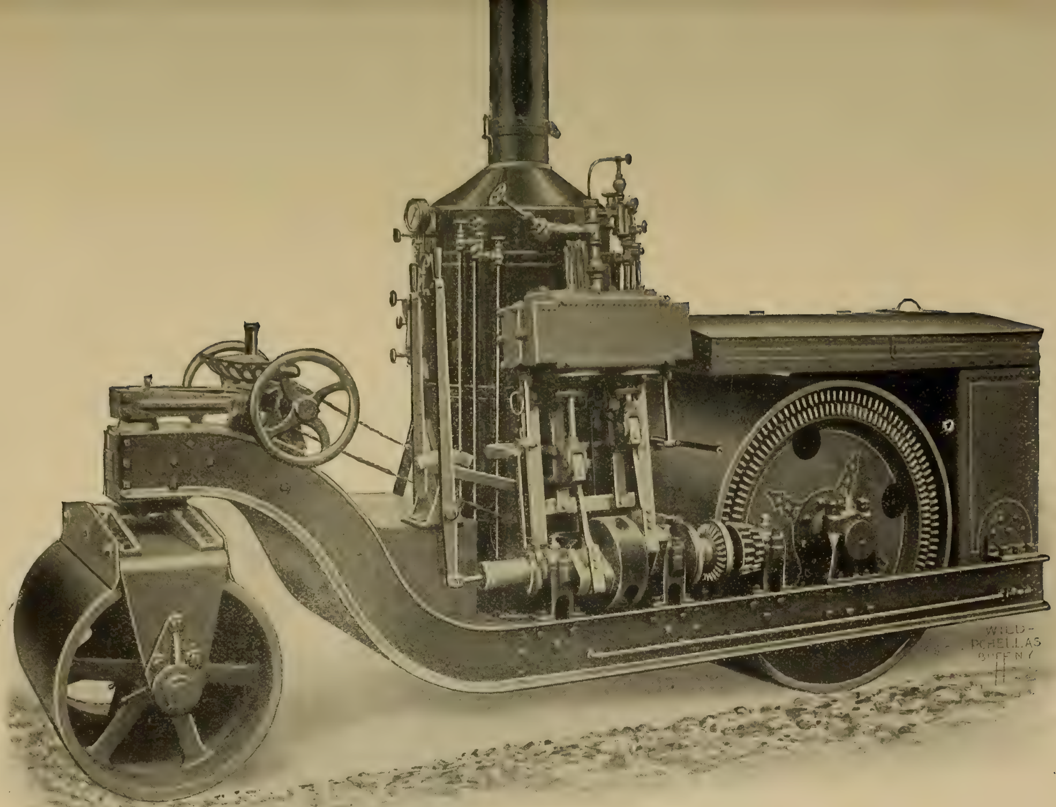

FIG. 23.—Asphalt Steam Roller, 8 Tons.

are joints to be made, between the work of different days, with the curb and with headers, around boxes, manholes, and similar protuberances, and with railway tracks or the brick or stone stretchers along them. It is also quite possible, owing to unavoidable circumstances, that the surface may be found to be, after its preliminary compression, too high at one point—in the gutter for example—or too low at another. Owing to chilling of the surface it may not close up properly or from inaccessibility to the roller fail to be sufficiently compressed. These conditions must be met and the defects remedied, all in their own way, and in many cases tools especially provided for the purpose, known as tampers and smoothers, must be used. These tools are shown with some others in the accompanying illustration, from the catalogue of the Iroquois Iron Works of Buffalo, N. Y. Fig. 24.

The tampers and smoothers must be used with great care and should not be too hot. If the smoothers are hot and it is difficult to tell their temperature in bright sunshine, they may do much damage by hardening the bitumen in the surface, and their use is only advisable in very skilful hands. They are a relic of the days when mixtures were used which would not close up readily on account of poor grading and deficiency in bitumen. With standard mixture they are seldom necessary except on joints. The tampers are not as dangerous, since they are not left in contact with the surface as long as the smoothers. They are used on joints, around manholes, and along rails at points which the roller cannot reach and in reducing inequalities in the gutter.

Attempts to reduce projections above the proper grade with tampers are rarely successful; the material at the point is merely more strongly compressed than that in the immediate neighborhood, with the result that the latter goes down under traffic and the original elevation is brought out again. Especially in gutters, where the surface is too high, the excess should be removed with a hot shovel, if necessary, after heating it with a smoothing iron. Except on joints between days' work, the use of tampers and smoothers is a makeshift to cover up poor raking, and the best street foreman will be the man who finds the least necessity for their

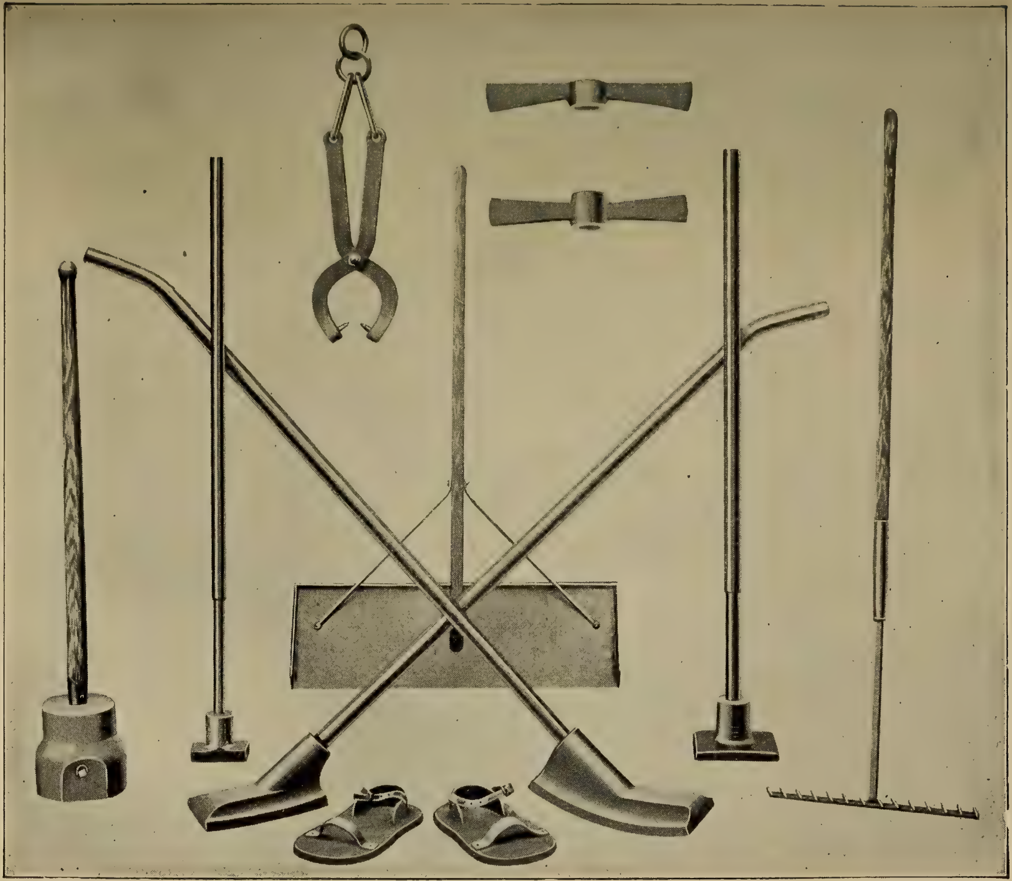

Fig. 24.—Hand Tools Used on Street.

use, especially that of the smoothers, for reasons which have been already mentioned.

Joints between different days' work, according to the preference of the street foreman, are made in different ways. Usually the mixture is compressed to a feather-edge under the steam-roller and left in this condition. On the following morning the feather-edge is cut back to a point where the full thickness of surface is shown. This edge is painted with melted asphalt and the joint between the two days' work is made in this way.

In the middle West an excellent joint is made by imbedding in the soft material, while still hot and after it has been raked off to a feather-edge, a rope of about $\frac{3}{4}$ of an inch in diameter to which a flap of canvas is attached. The steam-roller is run over this until final compression is obtained, and on the following day the rope and canvas are easily detached, leaving an excellent section to work to without the necessity of cutting back and losing good material. This form of joint is to be recommended.

SUMMARY.

The preceding chapter describes the method of transporting and handling on the street the surface mixture, together with the use of the tools employed in laying it.

PART VI.

THE PHYSICAL PROPERTIES OF ASPHALT SURFACES.

CHAPTER XXI.

RADIATION, EXPANSION, CONTRACTION, AND RESISTANCE TO IMPACT.

THE physical properties of asphalt pavements are of interest in two ways: first, from a general point of view as pertaining to asphalt surfaces as a whole, and, second, the peculiar characteristics which are dependent on particular mixtures according as they differ in sand grading, the amount and character of filler they contain, and the consistency and character of the cementing material with which they are bonded.

Radiation from Asphalt Pavements.—Asphalt pavements have been frequently criticised because of their great absorption of heat when exposed to summer suns in an atmosphere of high temperature and its radiation again during the ensuing night. With a view of determining the number of thermal units of heat thus absorbed and radiated numerous inquiries have been addressed to the author as to the specific heat of asphalt. It has been assumed that the specific heat of asphalt could not be very different from that of other native bitumens the records of which are available. For example, the specific heat of petroleum is given by Pagliani[1] as .498 to .511. It must be remembered, however, that but 10 to 11 per cent of an asphalt surface consists of bitumen; the remainder is quartz and mineral matter which has a specific heat no greater than .201. The specific heat of an asphalt-surface mixture cannot, therefore, be much greater than that of a granite pavement, or be the cause of any great difference in its temperature. That the asphalt pavement seems hotter must be due to other causes, and this is to be attributed to the fact that having a blacker surface it absorbs heat rather more rapidly than the granite and radiates it much more rapidly after sunset. There is, therefore, not much more heat given out by asphalt than by granite pavement, but since it may be given out more rapidly it may be more noticeable. Each form will give up about the same quantity during the entire night.

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[1] Atti di Torino, 1881, **17**, 97.

That the figures assumed for the specific heat of asphalt are not far out of the way may be seen from the following information furnished in "Municipal Engineering"[1] by Mr. A. W. Dow.

SPECIFIC HEAT.

Refined Trinidad asphalt	.350
Cuban asphalt cement	.401
Trinidad " "	.381
Bermudez " "	.413
Maracaibo " "	.447
Quartz sand	.201

Maracaibo and Bermudez asphalts, being nearly pure bitumen, afford the best idea of the true specific heat of asphalt. This factor is somewhat smaller than that for petroleum oil, and this is evidently due to the presence of more condensed molecules in the asphalt than in the oil.[2]

Some experiments conducted in the summer of 1907 with cylinders of granite, brick and asphalt surfaces, confirmed the previous conclusions, as will be seen from the following data:

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[1] 1904, July, 27, 22.

[2] Additional data in regard to the specific heat of mineral oils will also be found in "Petroleum," Berlin, 2, 521, April 3, 1907.

ABSORPTION AND RADIATION OF HEAT BY VARIOUS PAVEMENTS.

May, 1907.

Time.	Granite.		Brick.		Asphalt.	
	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.
10.30	72.0	....	73.4	....	72.0	....
11.30	93.2	+ 21.2	93.2	+ 19.8	91.4	+ 19.4
12.30	102.2	+ 30.2	101.3	+ 27.9	100.4	+ 28.4
3.00	98.6	− 4.6	101.3	+ 27.9	100.4	+ 28.4
4.00	84.2	− 18.0	86.0	− 15.3	86.0	− 14.4

June, 1907.

Time.	Granite.		Brick.		Asphalt.	
	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.
11.05	80.6	....	80.6	....	78.8	....
11.35	88.0	+ 7.4	90.6	+ 10.0	89.6	+ 10.8
12.05	91.5	+ 10.9	93.2	+ 12.6	92.0	+ 13.2
2.35	92.8	+ 12.2	93.6	+ 13.0	91.4	+ 12.6
3.05	87.8	− 5.0	89.4	− 4.2	87.8	− 3.6
4.05	84.2	− 8.6	84.2	− 9.4	84.2	− 7.2

June, 1907.

Time.	Granite.		Brick.		Asphalt.	
	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.	Thermom. Temp.	Gain or Loss.
11.15	81.5	....	83.4	....	82.4	....
11.45	89.6	+ 8.1	93.1	+ 9.7	93.1	+ 10.7
12.05	93.0	+ 11.5	96.8	+ 13.4	96.8	+ 14.4
2.05	103.8	+ 22.3	105.8	+ 22.4	105.8	+ 23.4
3.15	93.0	− 10.8	93.2	− 12.6	91.4	− 14.4
4.30	86.0	− 17.8	85.2	− 20.6	84.2	− 21.6

Black bulb thermometer in each case 90° F. to 98° F. in sun.
Air temperature, May, 73° F. to 84° F.
" " June, 81° F. to 92° F. and 81° F. to 93° F.
Clearer atmosphere on second day.

Expansion and Contraction of an Asphalt Surface.—Asphalt surfaces necessarily expand and contract with changes of temperature. As they consist very largely, to the extent of about 89 per cent, of mineral matter, this expansion must be closely that of quartz, of which the mineral aggregate is principally composed and must be fairly constant for all surfaces. Whether the cementing material is sufficiently strong to yield to such contraction without the fracture will determine whether the pavement cracks or not. It is, of course, a feature which will vary with the character of every mixture, depending upon its composition. This subject will be taken up in detail in a succeeding chapter, where the cause of cracks in pavements is considered.[1]

Impact Tests of Asphalt-surface Mixture.—The force which has the greatest tendency to injure an asphalt surface is that of impact. The blows from horses' hoofs or from the wheels of vehicles where the surface is irregular deteriorates it to a much larger extent than attrition or ordinary travel. A well-constructed asphalt surface has been known to carry without injury a load of 51 tons on a truck with broad tires, whereas the same pavement under constant impact would deteriorate perceptibly in the course of years.

The capacity of any asphalt surface to resist impact can be readily tested in the laboratory with appropriate testing machines, such as that devised by Mr. Logan Waller Page, of the Office of Public Roads, and described on page 34 of Bulletin No. 79 of the Bureau of Chemistry, and which is illustrated in Fig. 25. Cylindrical test-pieces are made from the surface mixture to be examined in a mold which permits of its being filled with the hot mixture at an appropriate temperature and of being compressed by means of blows with a hammer of four pounds weight, ten of which are given to each end of the cylinder. These cylinders are usually made 1.25 inches in diameter and 1 inch high, and weigh about 50 grams. When brought under the impact machine they are held firmly with a plunger resting on the surface with a spherical bearing having a radius of 4/10 of an inch. The hammer is then allowed to drop from a distance of 1 cm., and this distance is increased by this amount at each blow until the test-piece yields. Under these conditions tests have shown that the resistance of any asphalt surface to impact will depend upon:

1. The sand grading.
2. The character of the sand.

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[1] See page 480.

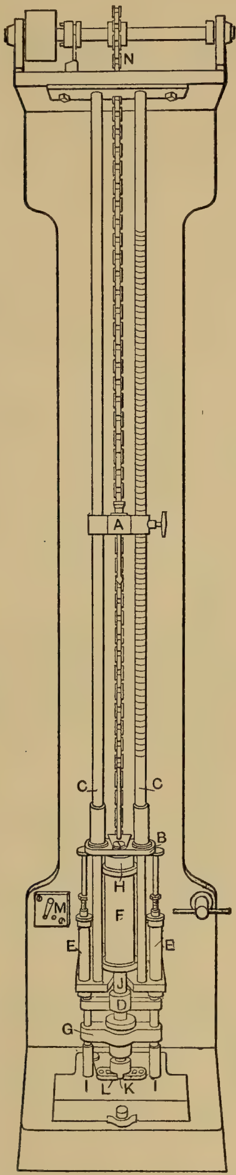

FIG. 25.—Instrument for Impact Test.

IMPACT TESTS OF ASPHALT SURFACE MIXTURES.

Test No.	Description.	No. of Blows Producing Crack.	Penetration of Plunger Inches.	Temperature of Test-pieces.	Density.	Bitumen.	Passing Mesh.								On 10	A. C. Penetration. Bowen
							200	100	80	50	40	30	20	10		
70354	Standard N. Y. Bermudez mixture	11	.040	40° F.	2.25	11.2	17.8	12	10	27	12	5	3	2	0	70
"	Do	19	.046	78° F.	2.24											
"	Do	24	.120	100° F.	2.24											
69645	Standard N. Y. Trinidad mixture	15	.028	40° F.	2.24	11.1	16.9	12	10	24	13	7	4	2	0	68
"	Do	29	.113	78° F.	2.26											
"	Do	24	.142	100° F.	2.25											
75692	Maracaibo and Texas asphaltic flux	18	......	40° F.	.....	11.5	15.5	11	9	27	12	6	5	3	0	80
"	Do	13	......	78° F.												
"	Do	10	......	100° F.												
75857	California residual pitch	12	......	40° F.	.....	11.0	15.0	12	7	26	16	5	5	3	0	80
"	Do	16	......	78° F.												
"	Do	14	......	100° F.												
75831	Gilsonite and Texas asphaltic flux	13	......	40° F.	.....	11.4	16.6	11	9	26	14	5	5	2	0	80
"	Do	24	......	78° F.												
"	Do	18	......	100° F.												
75801	Grahamite and Texas asphaltic flux	19	......	40° F.	.....	11.4	15.6	9	10	27	13	5	7	2	0	80
"	Do	15	......	78° F.												
"	Do	13	......	100° F.												
75375	Brooklyn, Cont. No. 2 (1904)	7	......	40° F.	.....	10.3	7.7	4	6	23	17	13	10	8	1	
"	Do	11	......	78° F.												
"	Do	14	......	100° F.												

IMPACT TESTS OF ASPHALT SURFACE MIXTURES.

Test No.	Description.	No. of Blows Producing Crack.	Penetration of Plunger Inches.	Temperature of Test-pieces.	Density.	Bitumen.	Passing Mesh.								On 10	A. C. Penetration. Bowen
							200	100	80	50	40	30	20	10		
75374	Brooklyn, Cont. No. 2 (1904)	7	. . . . . .	40° F.	. . . . .	10.8	8.2	5	2	14	11	13	12	13	11	
"	Do	9	. . . . . .	78° F.												
"	Do	19	. . . . . .	100° F.												
74417	Brooklyn, Cont. No. 2 . .	11	. . . . . .	40° F.	. . . . .	10.8	8.2	4	4	18	13	13	13	12	4	
"	Do	16	. . . . . .	78° F.												
"	Do	20	. . . . . .	100° F.												
. . . . .	Brooklyn, Cont. No. 3 . .	10	. . . . . .	40° F.												
	Do	16		78° F.												
	Do	8	. . . . . .	100° F.												
74461	Brooklyn, Cont. No. 4 (1904).	13	. . . . . .	40° F.	. . . . .	10.6	10.4	4	4	10	11	11	18	20	1	
"	Do	14	. . . . . .	78° F.												
"	Do	11	. . . . . .	100° F.												
. . . . .	Chicago, Ill.	8	. . . . . .	40° F.												
	Do.	16	. . . . . .	78° F.												
	Do.	17	. . . . . .	100° F.												
30828	Minneapolis, Minn. (1895)	6	.025	78° F.	2.27	8.7	11.3	10	12	34	17	4	2	1		
30831	Minneapolis, Minn. (1896)	16	.057	78° F.	2.22	9.5	12.5	11	13	31	15	5	2	1		
30830	Do	14	.053	78° F.	2.23	9.2	14.8	10	11	32	16	4	2	1		
14996	New York (1904)	12	. . . . . .	40° F.	. . . . .	12.0	7.0	5	5	16	12	11	12	20		
"	Do	15	. . . . . .	78° F.												
"	Do	13	. . . . . .	100° F.												
30035	Rochester, N.Y., (1885) .	7	.028	78° F.	2.23	8.3	13.7	15	10	20	13	9	6	5	. . . .	28

IMPACT TESTS OF ASPHALT SURFACE MIXTURES.

Test Number.	Location.	Density	Number of Blows Producing Crack.	Penetration of Plunger. Inches.	Bitumen.	Passing Mesh.								On 10	A. C. Penetration. Bowen.
						200	100	80	50	40	30	20	10		
73341	Brooklyn, N. Y.	2.27	20	.088	10.0	10.0	6	5	19	14	11	14	11	....	60
73394	Very coarse sand	2.23	21	.095	10.0	11.0	5	4	16	16	15	11	11	1	63
72417	Chicago, Ill.	2.37	28	.117	10.9	11.1	17	18	33	6	1	1	2	....	52
73273	Very fine sand	2.20	29	.147	10.9	11.1	16	17	33	6	2	1	2	1	58
73124	Harrisburg, Pa	2.20	28	.098	11.4	13.6	7	8	31	16	7	4	2	....	65
73374	Deficient in fine sand	2.20	25	.088	10.9	14.1	7	7	28	16	10	5	2	....	66
73323	Kansas City, Mo.	2.10	19	.060	8.9	21.1	12	14	17	3	2	4	14	4	
.....	Rock asphalt mixture	2.09	18	.057											
73371	Long Island City, N. Y.	2.29	29	.138	11.6	13.4	10	7	29	14	8	3	4	....	69
73456	Deficient in fine sand	2.23	28	.113	11.3	13.7	8	8	30	14	8	4	3	....	68
73315	New York City	2.18	31	.147	11.0	14.0	8	6	29	14	9	6	3	....	63
73382	High bitumen; deficient in fine sand	2.14	30	.113	11.6	13.4	9	6	27	14	10	6	3	....	67
71547	Niagara Falls, N. Y.	2.36	25	.129	10.2	13.8	11	13	27	13	6	4	2		
73396	High in 200-mesh	2.32	25	.129	10.4	15.6	12	12	27	9	7	3	3	1	60
73187	Pittsburgh, Pa	2.26	18	.056	10.2	14.8	10	10	33	10	4	4	3	1	80
73442	Deficient in fine sand	2.22	19	.057	10.5	13.5	7	8	38	9	6	4	3	1	76
.....	Seattle, Wash.	2.24	18	.065	12.0	16.0	17	12	20	11	6	4	2	....	80
.....	High oil bitumen	2.21	14	.060											
72358	Spokane, Wash	2.23	17	.057	13.2	11.8	14	10	19	8	8	8	8	....	65
72648	Very high oil bitumen	2.23	18	.063	13.0	12.0	15	10	19	9	7	9	6	....	64

3. The amount of filler present.
4. The character of the asphalt in use.
5. The consistency of the asphalt.
6. The density and degree of compaction of the test-piece.
7. The percentage of bitumen in the mixture.

The data in the preceding tables will illustrate the application of the test.

From these results it appears that the old-time mixtures which are low in bitumen, those from Minneapolis and Rochester, do not withstand impact to nearly the extent that the more modern mixtures do, and reveal the cause of the inferiority of the pavements constructed with such mixtures.

The results of tests by impact at different temperatures of the standard New York mixture made with various asphalts show that those in which Trinidad lake asphalt is the cementing material give a much greater resistance to impact at low and medium temperatures, and are much less affected by temperature changes than those made with Bermudez asphalt, while the variation in the character and grading of the sand, and the percentage of filler and of bitumen, are made evident by other data in the table.

It should also be observed that the work done in fracturing the test-pieces is relatively as the square of the number of blows.

The impact test is also valuable in revealing the difference in susceptibility to water action of different mixtures. Cylinders of standard Trinidad and Bermudez asphalt mixtures were prepared and some of them tested by impact at 78° Fahr. as soon as made. Others were immersed in water for three months and the

	Trinidad.	Bermudez.
Density	2.24	2.24
Number of blows:		
Original material	21	16
After three months' exposure to running water	20	13
Water absorbed:		
Pounds per square yard	.129	.157

amount absorbed determined, after which they were subjected to the impact test. The results are shown in the table at bottom of page 433.

It is readily seen that the Bermudez mixture is much more weakened by immersion in water than that made of Trinidad asphalt. The value of the impact test is, therefore, assured from the results thus far obtained and the investigation of the subject will be carried out in greater detail in the future.

SUMMARY.

In the preceding pages the question of the radiation of heat from asphalt pavements, their expansion and contraction, and resistance of various asphalt surface mixtures to impact are considered.

PART VII.

SPECIFICATIONS FOR AND MERITS OF ASPHALT PAVEMENTS.

CHAPTER XXII.

SPECIFICATIONS.

As has already been mentioned, the specifications for the construction of asphalt pavements which are prepared by engineers who are not thoroughly acquainted with the subject are often wanting in some respects or make certain requirements which are undesirable, unessential, or unnecessarily increase the cost of the pavement. For the construction of an asphalt pavement which is to meet the requirements of ordinary traffic in a majority of our cities the following, in the author's opinion, will be found to be a thorough protection of the city's interests, and not open to objection by the bidders that the provisions are unreasonable.

SPECIFICATIONS FOR ASPHALT PAVEMENT ON PORTLAND-CEMENT CONCRETE FOUNDATION.[1]

Extent of Work.—The work shall consist of regulating and grading the entire street, constructing combined curb and gutter, laying asphalt pavement, and all work incidental thereto, all in accordance with the following specifications:

Removal of Old Materials.—All old material which is not to be used in the work, shall become the property of the contractor and be removed by him.

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[1] As an example of the type of specifications in actual use in cities, those portions of the specifications of Kansas City, Mo., which apply to the technical portion of the work are presented in an appendix.

GRADING.

Excavation, Grading and Preparation of Foundation.—Any old material to be used again shall be compactly piled on the side of the roadway. The excavation shall be carried to the grade established by the Engineer. When completed, the sub-grade shall present a line and contour parallel with and approximately ....inches below the surface of the finished pavement to be constructed. Should any soft, spongy, vegetable or other objectionable matter be disclosed by the excavation thus made, or be located where filling is to be done, such material shall be removed and replaced with suitable material, which shall be thoroughly compacted. Whenever deemed necessary by the Engineer, the sub-grade shall be rolled with a suitable steam roller.

Inspection and Piling of Material.—The materials for construction, when brought upon the street, shall be neatly piled so as to present as little obstruction as possible to travel. No material shall be used without the approval of the Engineer, the contractor furnishing all labor necessary for inspection, without any charge.

Filling and Embankments.—Embankments shall be brought up to the designated grades, and the top shaped off and compacted as defined for earth excavation. Such excavated material as may be fit for the purpose and as may be necessary, shall be used to fill in those parts of the streets which are below the aforesaid grades.

CONCRETE.

Upon the sub-grade, prepared as above described, Portland-cement concrete composed of Portland cement, clean sharp sand, and broken stone or slag, will be laid to an average thickness of ......inches. Suitable gravel may be used in combination with the stone or slag, as hereinafter provided. The cement shall be of the best quality of American manufacture and shall be submitted to the Engineer for inspection at least ten (10) days before it is used. It shall conform to the following tests, conducted according to the methods recommended by the Committee on Uniform Tests of Cement of the Am. Soc. of C. E. It shall not set in less than one (1) hour. When mixed in the proportion of one (1) part of cement, by weight, and three (3) parts of standard sand, it shall have a tensile strength after exposure of one (1) day in air and six (6) days in water of at least one hundred and fifty (150) pounds.

The sand shall be clean and sharp, not more than 20 per cent of which shall pass a 50-mesh screen. It shall be free from loam adherent to the sand grains. The gravel shall be of such size that it will satisfactorily fill the voids in the broken stone, and it shall not contain dirt or foreign matter. The broken stone shall consist of granite, trap, or other hard rock or slag which shall be satisfactory to the Engineer. It shall be of such a size that all will pass through a revolving screen, having holes two and one-half (2½) inches in diameter, and be retained by a screen having holes one-half (½) inch in diameter. Stone which is the run of the crusher may be used when provision is made for the consideration of finer particles than one-half (½) inch which it contains as sand. The unit of measure in mixing these materials will be the barrel of cement, weighing 380 pounds, and four (4) cubic feet for sand, gravel, and stone. They shall be mixed in the following proportions and in the following manner:

The sand and cement shall be mixed dry in the proportion by volume of one (1) of cement to three (3) of sand, and then made into a mortar by the addition of water. To this mortar will be added six (6) measures of wet broken stone, and the whole thoroughly mixed by hand or machinery until it is entirely uniform.

Where gravel is available this may be used in such proportion that the gravel will fill the voids in the broken stone, with a consequent decrease in the amount of mortar necessary to make a compact concrete. For example: A one (1) to three (3) mortar which could be mixed with only six (6) parts of broken stone may be mixed with a combination of two (2) to three (3) parts of gravel and four (4) to six (6) parts of broken stone. The concrete thus mixed will be of such a consistency, owing to the percentage of water which it contains, that it shall quake very slightly when thoroughly rammed.

The concrete as thus prepared shall then be spread on the sub-grade and rammed, the surface being so graded that in its finished condition it shall average....inches below that of the finished pavement. No concrete shall be used that has been mixed more than one hour.

The concrete, after laying, shall be properly protected and the surface shall be kept moist in warm weather by sprinkling at proper intervals.

At the expiration of such a period as is found to be necessary in order that the concrete shall have attained a sufficient set to sustain a steam roller, the binder course shall be laid.

ASPHALT PAVEMENT.

Definition.—The pavement proper shall consist of a binder course....inches in thickness and a wearing surface....inches in thickness, equal in composition to the pavement mixture hereinafter described.

BINDER COURSE.

The alternative of an open or close binder course is given. In any specification but one should be called for. The close binder course is much more desirable.

Open Binder.—*Stone.*—The binder shall be composed of suitable clean broken stone passing a one and a quarter (1¼) inch screen.

Asphaltic Cement.—The stone shall be heated in suitable appliances, not higher than 300° Fahrenheit, and then thoroughly mixed by machinery with asphaltic cement equivalent in composition to that hereinafter set forth, in such proportion as will cover the stone with a glossy coat and without any excess of asphaltic cement.

Laying.—The binder must be hauled to the work and spread while hot upon the foundation to such thickness that, after being immediately compacted by rolling, its average depth shall be....inches, and its upper surface shall be approximately parallel to the surface of the pavement to be laid. Upon this binder course shall be laid the wearing surface.

No traffic, except such as may be required in depositing the surface mixture or in otherwise prosecuting the work, shall be allowed on the binder course.

Compact or Close Binder.—Compact or close binder shall be composed of hard, clean broken stone which shall pass an opening one (1) inch in diameter, the voids in which are filled with finer stone passing an opening three-eights ($\frac{3}{8}$) inch in diameter, while the voids in the mixed stone shall be filled with a well graded sand or old asphalt surface mixture which has previously been in use, and which has been softened by heating so as to allow it to be incorporated properly with the stone. If sand is used, sufficient asphalt cement shall be added to thoroughly coat the mineral aggregate with bitumen without showing any excess on compression with a hot tamper, while if old surface material is used, sufficient cement shall be used to coat the stone and produce the same result.

Care should be exercised with close binder that it does not carry an excess of fine material or of asphalt cement, as in this case the wearing surface of the pavement may have a tendency to displacement.

Asphaltic Cement.—The asphaltic cement for the binder course should have a consistency of at least twenty (20) points, as indicated by the Bowen machine, higher than that in use in the surface.

Pavement Mixture.—The pavement mixture for the wearing surface shall be composed of:

(*a*) Asphaltic cement (Refined asphalt and flux).
(*b*) Sand of satisfactory grading and grain.
(*c*) Filler, consisting of finely powdered mineral matter.

Asphaltic Cement.—The asphaltic cement shall be composed of refined asphalt and flux of such character that the bitumen, without regard to the mineral matter present, shall be a homogeneous solution, and present the following characteristics:

1. The proportion of bitumen soluble in 88-degree naphtha

shall not exceed seventy-eight (78) per cent, nor fall below sixty-four (64) per cent.

2. A No. 2 needle, weighted with one hundred (100) grams, shall penetrate, in five (5) seconds, at 78° F., a distance of from three (3) to nine (9) millimeters.

3. When twenty (20) grams are heated in a receptacle about two and a half (2½) inches in diameter and about two (2) inches high, for seven (7) hours, in an oven maintained at a uniform temperature of about 325° F., as determined by a thermometer, the bulb of which is immersed in a similar receptacle filled with oil, it shall not lose more than four (4) per cent. Its flash point as determined in a New York State closed oil tester, shall not be less than 350° F.

4. Ninety-five (95) per cent shall be soluble in carbon disulphide at air temperature, and not more than one and a half (1½) per cent of the bitumen shall be less soluble in carbon tetrachloride than in carbon disulphide, the test for the former being conducted by submitting the bitumen to the action of the tetrachloride for twenty-four (24) hours before filtration.

Sand.—The sand shall consist of hard grains, not necessarily sharp, but not containing more than one (1) per cent of clay or loam. On sifting, the entire amount shall pass a ten (10) mesh screen, at least fifteen (15) per cent shall pass an eighty (80) mesh screen, and seven (7) per cent a one-hundred (100) mesh screen.

Filler.—1. *Powdered Mineral Matter or Dust.*—The filler shall consist of ground limestone or any other mineral matter of sufficient density to produce a powder having a volume weight of at least ninety (90) pounds to the cubic foot. It shall be so fine that at least sixty-six (66) per cent shall pass a two-hundred (200) mesh screen, and all of it shall pass a fifty (50) mesh screen, while, when thoroughly agitated with distilled water at a temperature of 68° F., by means of an air blast, avoiding cyclonic effects, not more than forty (40) per cent shall subside on standing for fifteen (15) seconds.

2. *Portland Cement.*—The filler shall consist of Portland

cement of such a degree of fineness that seventy-five (75) per cent will pass a two-hundred (200) mesh sieve.

Only one or the other of the materials described as filler should be called for in any specification, as the difference in cost between the two is sufficient to require a separate estimate on each.

Combining Materials.—The materials complying with the above specifications shall be mixed in proportions by weight, depending upon their character. The percentage of matter soluble in carbon disulphide in any pavement mixture shall be not less than 9.5 nor more than 12.0 per cent.

The sand and the asphaltic cement will be heated separately to such temperatures that the finished mixture shall, depending on the asphalt in use, have a temperature of from 290° to 330° Fahr. The filler shall be mixed, while cold, with the hot sand. The asphaltic cement will then be mixed with the sand and stone dust, at the required temperature and in the proper proportion in a suitable apparatus, so as to effect a thoroughly homogeneous mixture.

Laying the Pavement.—The above mixture shall be hauled to the street in trucks properly protected from radiation by tarpaulins at a temperature of not less than 250° Fahr., and spread upon the binder to such a depth as will insure an average thickness of .... inches after ultimate compression. This compression will be attained by first smoothing the surface with a hand-roller, or light steam-roller, after which hydraulic cement or stone dust shall be swept over it, when the rolling will be continued with a steam-roller until the surface is properly compacted.

BITUMINOUS CONCRETE PAVEMENT.

For a bituminous concrete surface, the character of the asphalt cement, sand, filler and stone will be the same as those provided for in the previous specifications.

Determination of Proportions.—The wearing surface mixture shall be composed of the materials previously specified combined in proportions to be determined as follows:

The stone shall be separated into fragments which are retained and those which pass a screen with circular openings of three-eighths (⅜) inch size. While hot, a layer of the coarser fragments are to be spread on the bottom of a strong box exactly one foot square and shaken down. Hot fragments of the smaller size are then shaken into the voids in the larger stone until the latter are filled. Into this mixture hot sand and filler, in the proportion of ninety (90) per cent sand and ten (10) per cent filler, are sifted, with continued jolting and jarring of the box, until the stone has taken up all of the fine material possible. This operation is repeated with subsequent layers until the box is full. It is then struck off evenly and weighed. The total weight of the mineral matter in the box obtained in this way is divided by the weight of a solid cubic foot of mineral matter of the same density, and the voids in the mixture of rock, sand and filler determined. The voids should not exceed 25 per cent.

The proportions by weight in which the different components are present is then determined either by screening the contents of the box or by originally taking a definite amount of each and determining by difference the amount actually placed in the box. These proportions shall be those which shall be subsequently used in making up the mineral aggregate for the surface mixture unless observation on the street in laying the mixture should indicate the necessity for increasing the amount of fine material present.

The proportions will ordinarily vary between the following limits:

Coarse stone	56 to	30%
Fine stone	16 "	26
Sand	25 "	33
Filler	3 "	5

The variations will depend upon the shape of the fragments of the coarse stone and on the uniformity in size of the fragments of the two dimensions.

The amount of bituminous cement necessary to coat the particles of the above mineral aggregate and fill the voids therein as nearly as possible, shall be determined as follows:

To the hot mineral aggregate assembled in the proportions arrived at as above, shall be added the bituminous cement in an amount which previous experience points out as within the limits for such a mixture. After thorough mixing the material prepared in this way is placed upon a firm surface (such as one of hydraulic concrete) and compacted with a hot tamper until it is thoroughly compressed. If bitumen comes to the surface to a slight extent, the amount used is satisfactory, but if it appears in excess, the amount of bituminous cement must be diminished, or, if it appears dry, it must be increased until the proper appearance is obtained. The percentage thus determined will be followed in making the surface for the street, but it may be modified to a certain extent to correspond to unavoidable variations in the mineral aggregate, but in no case shall it exceed 8.0 per cent, nor fall below 6.5 per cent.

Preparation and Mixing of Bituminous Wearing Surface.—The sand and stone shall be heated in suitable heaters to the required temperature, which temperature shall be dependent upon that of the atmosphere at the time the mixing is in progress, and upon the character of the bituminous cement in use. These materials, while in this heated condition, shall be separated into not less than three sizes by passing over a screen having perforations or openings of at least two diameters, so arranged as to separate the stone and sand into particles larger than three-eighths ($\frac{3}{8}$) inch in their greatest diameter, particles passing a screen with openings three-eighths ($\frac{3}{8}$) in size and retained on a 10-mesh screen, and particles passing the latter screen; the material of each size being collected separately in suitable bins. The material of each size shall then be weighed or measured out in the proportions determined upon, together with a proper proportion of filler (finely ground mineral matter) not previously heated. The aggregate shall then be mixed with the bituminous cement, prepared as described in the paragraph on this material above given, in a suitable mixing appliance, either pans or a double-bladed revolving mixer of the type generally used in the preparation of bituminous paving mixtures, the operation of mixing to be continued until uniformity is attained.

Laying Bituminous Wearing Surface.—In this condition the bituminous wearing surface mixture shall be hauled to the street in suitable carts or wagons, properly protected from the weather, so as to prevent an undue loss in temperature. It shall be spread upon the foundation with hot rakes to such a depth that after receiving its ultimate compression by rolling with a steam roller, it will have an average thickness of two (2) inches.

Surface Finish.—After the rolling of the bituminous wearing surface has been completed, there shall be spread over it a thin coating of quick-drying bituminous flush-coat composition, specially prepared, the purpose of this coating being to thoroughly fill and smooth out any unevenness which may be on the surface of the coarser mixture.

There shall then be spread over and rolled into the wearing surface a thin layer of coarse sand or stone chips for the purpose of presenting a gritty surface, which shall not be slippery. The character and size of the sand or stone chips to be spread upon the surface, and the consequent degree of roughness of surface, shall be determined by the Engineer, who may, at his discretion, omit the use of stone chips and substitute therefor a light sweeping of hydraulic cement, stone dust, or similar material, in order to secure a smoother surface.

Material for Repairs.

Repairs.—In case of repairs, it shall be required that such repairs be made with a pavement mixture equal to the above described.

Clearing Up.

All surplus materials, earth, sand, rubbish, and stones are to be removed from the line of the work. All material covering the pavement and sidewalks shall be swept into heaps and immediately removed from the line of the work.

MAINTENANCE.

Contractor to Make Repairs.—The contractor shall make all repairs which may be necessary during a period of ....years[1] from the date of acceptance of the pavement, which are caused by improper construction due to defective materials or workmanship, and he guarantees that he will repair during this period, any and all defects arising through its usual use as a roadway. In case of the contractor's failure or neglect to do so within thirty days after notification by the duly authorized official, such notice to be served upon him in writing, either personally or by leaving said notice at his place of business or with his agent in charge of the work, the said duly authorized official may repair, or cause such defects to be repaired, and may recover cost thereof from the contractor or his sureties.

Temporary Repairs in Winter.—The contractor shall have the right, in case of trenches, to provide against settlement by covering the surface of the cut with broken stones and maintaining the surface for a sufficient period, and during winter weather any hole in the pavement may be filled and maintained with binder, asphalt mastic, or other suitable material.

Repairs to Openings.—During the period of maintenance, the contractor shall, within thirty (30) days after the receipt of notice so to do, restore the pavement over all openings made under permits legally issued by the duly authorized official for new service connections, or repairing, renewing, or removing the same, and over all trenches made for carrying sewers, water or gas pipes or any other sub-surface pipes or conduits, for the sum of $3.50 per square yard for any opening less than ten (10) square yards in area, and $3.00 per square yard over any trench measuring more than ten (10) square yards in area; $3.25 per square yard for restoring the pavement over any opening between or alongside of surface railroad tracks which shall exceed ten (10) square yards in area, and in case of any injury to the surface of the pavement caused by fire or accident, same shall be replaced for the sum of $2.00 per square yard. The concrete foundation, if relaid, shall be of the same thickness as that originally laid. The contractor will not be held responsible, during the period of guaranty, for any defects in the pavement or materials, which may have been caused by the opening of trenches or by the improper backfilling of the same, and will not be compelled to do the repaving over said trenches, except as hereinbefore provided, nor shall he be held responsible for deterioration of the pavement along the rails of street railway tracks, if the form of construction is such that the rail vibrates under the traffic it carries, unless the track construction has been in charge of the contractor himself, nor shall he be obliged to replace cracks in the surface, unless they have resulted in the disintegration of the surface.

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[1] The author has suggested no definite period of guaranty as there is a tendency on the part of the larger cities to shorten this to a very considerable extent, New York, Chicago, Philadelphia, and St. Louis now calling for five years, while in the State of California no guaranty whatever is required. Shorter periods are called for in view of the fact that municipal officials are now in a position to judge of the character of the work that is being done on any contract before acceptance, which was not the case years ago.

CEMENT CURB AND GUTTER.

Cement curb and gutter shall be composed of concrete formed as follows:

One (1) part of Portland cement.

Three (3) parts of clean sharp sand, or other suitable material.

Five (5) parts of crushed stone.

Cement and Sand.—Cement and sand shall be equal to the materials hereinbefore described for use in concrete foundation.

Stone.—The crushed stone shall be clean, free from dirt, and crushed to such size as to measure not more than one (1) inch in any dimension. It shall be deposited at the site of the work in such manner as to insure its cleanliness.

Foundation.—The curb and gutter composed of the above materials shall rest on a foundation of cinders six (6) inches in thickness after being thoroughly compacted by ramming.

Dimensions. — The gutter flag shall be eighteen (18) inches wide and five (5) inches thick; the curb shall be six (6) inches thick throughout, except at the upper face corner, which is to be rounded to a radius of one and one-half (1½) inches. The height of the curb above the gutter flag shall be....inches, all as shown on plans.

Finish.—All exposed surfaces shall be covered with a finishing coat of mortar three-eighths (⅜) inches in thickness, composed of one (1) part of cement thoroughly mixed with one and one-half (1½) parts of sand.

Before the concrete sets, the curb and gutter shall be cut into sections not exceeding six (6) feet in length.

Construction.—The curb and gutter as hereinbefore described shall be constructed at the grade and to lines established by the Engineer, ...feet from and parallel with the centre line of the street, except at intersections of streets and alleys, at which points it shall be returned to the street line, the necessary circular sections being built to radii established by the Engineer. The curb shall be properly back-filled to the top thereof.

PROPOSALS.

Bidders will be required to make proposals on blank forms furnished by the Engineer, which proposals shall state:

A price per cubic yard for excavation;

A price per cubic yard for embankment or filling;

A price per cubic yard for hauling excavated material or material for use in embankment, for each 1000 feet in excess of one-half mile;

A price per lineal foot for straight combined curb and gutter;

A price per lineal foot for circular combined curb and gutter.

An inclusive price for asphalt pavement, including foundation, open or close binder, and wearing surface, together with maintenance for a period of....years.[1]

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[1] Attention must be called to the fact that propositions for the use of one kind of binder alone and one type of filler alone should be preferably specified for any one street. If they are both specified, there should be some provision for alternative bidding.

An inclusive price for bituminous concrete pavement, including foundation and a bituminous concrete surface, with maintenance for a period of. . . .years.[1]

Other Specifications.—Specifications of another type will be found in the appendix, those issued by Kansas City being characterized by demanding an asphalt cement of a certain character without regard to the fine material from which it is made, and are, on this account, much to be recommended from many points of view.

Clay Soils in Cold Climates.—Although the preceding specifications are, as has been said, satisfactory in the majority of instances there are cases where, owing to the character of the climate, sub-soil, or heavy traffic to be carried by the pavement, special provisions must be made. On clay sub-soil in cold climates some special provisions, such as are made in Manitoba, may be desirable in the treatment of the sub-soil base. Such a provision may be outlined as follows:

In clay soils trenches shall be dug across the line of the street from the centre to the trenches in which the curb is laid on each side of the street, to a depth of six (6) inches and filled with broken stone or large gravel. The entire roadbed will then be thoroughly rolled with a steam roller, having a tread of at least (60) inches and a pressure per linear inch of tread of at least 310 pounds, along the large roll, until it is compacted. All soft spots which are developed should be refilled and rerolled. The surface thus prepared must conform closely to the prescribed cross-section of the street.

Upon this foundation, broken stone, preferably the run of crusher, gravel or clean sand, will be laid to the depth of three (3) inches and thoroughly consolidated by rolling, to be followed by the hydraulic concrete, the latter in this way not being brought in contact with the soil and drainage being provided by the broken stone.

This form of construction is most necessary in very cold climates and especially on clay soils where a thaw is apt to occur from the action of frost, and where cracks have been observed to open in the ground and extend through the concrete and the asphalt surface.

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[1] See footnote on page 447.

As an additional precaution under such conditions the following provisions are made as to setting the curb:

Curbing.—Curb of the character described shall be set in concrete in a trench....inches deep, the bottom of which is filled with broken stone to a depth of....inches, connected with the broken stone cross trenches of the base, upon which shall rest the concrete foundation for the curbstone, not less than six (6) inches thick and seventeen (17) inches wide, made of the materials in the proportions previously described for the concrete base, except that the stone shall not exceed one and one-quarter ($1\frac{1}{4}$) inches in maximum dimension. The curb shall be imbedded immediately in the centre of this concrete and backed up with additional concrete for a width of six (6) inches, extending from the concrete base to within four (4) inches of the top of the curb. The broken stone underlying the concrete shall be graded to catch-basins for the removal of ground-water.

Sandy Soils.—On sandy soils at the seashore, where it is difficult to compact the sand under the roller, it may be provided that a course of one (1) or two (2) inches of gravel or other suitable material may be spread and rolled over the sand before the concrete foundation is constructed

Asphalt.—While, in the author's opinion, there is no question that the best asphalt surface, in the present state of the industry, can be constructed with Trinidad lake asphalt or gilsonite, he would not be understood to affirm that satisfactory work cannot be done with other bitumens, and for streets of light traffic the Engineer may exercise such choice as he may believe to be desirable from the point of view of competition. He should, however, bear in mind that the skill which the contractor may possess and his knowledge of the art of constructing an asphalt pavement is of as great importance as the materials in use or the price which may be bid. At an equal cost the pavement constructed with skill and intelligence may be worth a very much larger sum when completed than another surface carelessly constructed. These points should weigh largely in the awarding of contracts if the cost of maintenance of the surface to the city after the expiration of the guarantee period is to be considered.

Grades of Streets on which Asphalt Pavements may be Constructed.—The general impression has gained ground, very naturally, that asphalt pavements are unsuited to grades of more than 4 to 5 per cent. That this is an erroneous conclusion may be seen from the fact that in 1890 an asphalt surface was laid in Washington, D. C., on Thirty-fourth Street, N. W., from M Street to Prospect Street, 275 feet long, the grade of which is 9.74 per cent, and that in Kansas City, Mo., the following streets have been constructed with the grades given.[1]

GRADES IN KANSAS CITY, MO., FOR ASPHALT PAVEMENTS.

Year Laid.	Street.	Grade.
1898	Jefferson Street, 18 to 20.	12.5%
1895	11 Street, Maine to Wyandotte. .	7.5
1897	Troost Ave., 19 to Belt Line. . . .	8.0
1895	Central Street, 16 to 17.	10.0
1894	Forest Ave., Independence to 8.	8.0

All of these streets are in constant use and are satisfactory except on occasions where a thin coating of moisture has become congealed on the surface. Several of the streets in Kansas City are only paved with asphalt in the centre, the sides having a stone or brick surface. Nevertheless, the asphalt surface is universally used in preference to the brick or stone, and appears to be no more slippery even under the most trying conditions. Where a film of ice causes asphalt to be slippery traffic is diverted to other streets with lighter grades, rather than to the brick or stone. As a matter of fact the limiting conditions in determining the extent to which the steepness of a grade will prevent the use of an asphalt surface mixture will depend entirely upon the climate and the nature of the traffic which uses the street. Eight per cent is not an excessive grade under ordinary eastern conditions, while in a climate like Seattle, Wash., a 10 per cent or 12 per cent grade is quite possible.

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[1] Tillson cites a grade of 17 per cent on a portion of Bates Street, in Pittsburg, Pa., and 12½ per cent in Scranton, while Baker mentions one of 16 per cent in San Francisco, Cal.

Crown or Camber.—That an asphalt pavement should show in transverse section a proper profile for the surface is as important as that the grade should be sufficient to provide for proper drainage. There is little agreement among engineers in regard to what this proper form should be, but it is quite certain that the tendency in America is to make all the asphalt pavements much too flat. Theoretically, no doubt, an asphalt pavement should demand but a low crown or camber. In practice, however, the pavement will prove much more satisfactory and pleasing to the eye if this is maintained at a comparatively high figure, since in wet weather the slight depressions which it is impossible to avoid in laying such a surface, or which are formed by unequal compression and traffic, will not then be revealed as small pools of water. This is especially the case if the profile of the surface shows a plane surface from the gutter to the crown instead of a curve.

It is generally assumed that for a roadway 30 feet wide a crown of 4 inches should be adopted, with a curve towards the gutter having a somewhat greater fall near the latter and decreasing towards the crown. The objection to this profile is that the street is too flat on the crown, with the result that depressions form there which retain water. It is, therefore, much better to keep the crown raised sufficiently to avoid this. On the other hand, with a nearly flat crown, the centre of the street which is used principally for traffic is of a more acceptable form. Mr. G. W. Tillson[1] gives the following table showing the necessary crown for streets of a width from 24 to 60 feet.

Width of roadway.......	24 ft.	30 ft.	30 ft.	36 ft.	48 ft.	60 ft.
Crown.................	3 ins.	4 ins.	6 ins.	5 ins.	6 ins.	8 ins.
Fall towards gutter in central $\frac{1}{3}$ of roadway......	$\frac{1}{3}$ in.	$\frac{4}{9}$ in.	$\frac{2}{3}$ in.	$\frac{5}{9}$ in.	$\frac{2}{3}$ in.	$\frac{8}{9}$ in.
Rate per 100............	$8\frac{1}{3}$ ins.	9 ins.	$13\frac{1}{3}$ ins.	$9\frac{1}{4}$ ins.	$8\frac{1}{3}$ ins.	$8\frac{8}{9}$ ins.
Fall towards gutter in second $\frac{1}{3}$ of roadway......	1 in.	$1\frac{1}{3}$ ins.	2 ins.	$1\frac{2}{3}$ ins.	2 ins.	$2\frac{5}{9}$ ins.
Rate per 100............	2′ 1″	2′ 3″	3′ 4″	2′ 4″	2′ 1″	2′ 3″
Fall to gutter in $\frac{1}{3}$ of roadway adjacent to curb. .	$1\frac{2}{3}$ ins.	$2\frac{2}{9}$ ins.	$3\frac{1}{3}$ ins.	$2\frac{7}{9}$ ins.	$3\frac{1}{3}$ ins.	$4\frac{5}{9}$ ins.
Rate per 100............	3′ 6″	3′ 8″	5′ 6″	3′ 3″	3′ 6″	3′ 9″

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[1] Street Pavements and Paving Materials, 202.

The author would regard an 8-inch crown as none too high for a 60-foot roadway, while on many flat streets a 6-inch crown is not too high for a 30-foot roadway. Of course the steeper the grade of the street the smaller the height of crown which is necessary, and this fact does not seem to have been taken into consideration in the table which Tillson offers.

In Paris, France, the crown for asphalt streets is determined by the formula, Fig. 26.

Provision is made for a drop of 10 per cent from the point *A* towards the curb for a space of 50 cm. (19.7 inches). This latter provision seems to the author to be an excellent one and, from his experience in Paris, the form of street profile to be a very successful one.

Baker[1] gives a resumé of the specifications of various cities for crowns of asphalt pavements to which the reader may refer. The provisions of the City of Omaha are also very excellent.

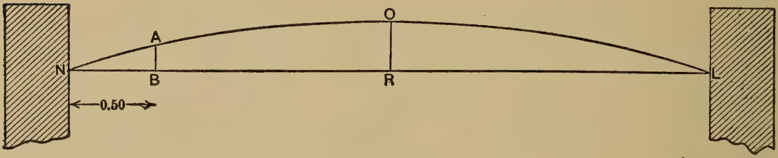

FIG. 26.

$$OR = 0.012\frac{NL^2}{NL-1},$$

$$AB = 0.05 \text{ meters.}$$

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[1] Roads and Pavements, 348.

TABLE OF STANDARD CROWNS.

(City Engineer's Office, Omaha, Neb., 1902.)

Distance Between Curbs.	Crowns for American Sheet Asphalt Pavement in Feet.												
	Grade of Street.												
	Level	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%
20 feet....	.40	.38	.37	.35	.34	.32	.30	.29	.27	.26	.24	.22	.21
25 “	.50	.48	.46	.44	.42	.40	.38	.36	.34	.32	.30	.28	.26
30 “	.60	.58	.55	.53	.50	.48	.46	.43	.41	.38	.36	.34	.31
35 “	.70	.67	.64	.62	.59	.56	.53	.50	.48	.45	.42	.39	.36
40 “	.80	.77	.74	.70	.67	.64	.61	.58	.54	.51	.48	.45	.42
45 “	.90	.86	.83	.79	.76	.72	.68	.65	.61	.58	.54	.50	.47
50 “	1.00	.96	.92	.88	.84	.80	.76	.72	.68	.64	.60	.56	.52
55 “	1.10	1.06	1.01	.97	.92	.88	.84	.79	.75	.70	.66	.62	.57
60 “	1.20	1.15	1.10	1.06	1.01	.96	.91	.86	.82	.77	.72	.67	.62
65 “	1.30	1.25	1.20	1.14	1.09	1.04	.99	.94	.88	.83	.78	.73	.68
70 “	1.40	1.34	1.29	1.23	1.18	1.12	1.06	1.01	.95	.90	.84	.78	.73
75 “	1.50	1.44	1.38	1.32	1.26	1.20	1.14	1.08	1.02	.96	.90	.84	.78
80 “	1.60	1.54	1.47	1.41	1.34	1.28	1.22	1.15	1.09	1.02	.96	.90	.83

NOTE.—The formula used for the construction of the table is as follows:

$$C=\frac{W(100-4f)}{5000};$$

C = crown of pavement in feet;
W = distance between curbs in feet;
f = number of feet fall per 100 feet of street.

Note.—Where the crown is less than 0.5 foot make the gutter 0.5 foot, and where it is 0.7 foot make the gutter 0.7 foot, and for intermediate crowns make the gutter equal the crowns.—Andrew Rosewater, M. Am. Soc. C. E., City Engineer.

None of these methods of arriving at a proper figure for crown is applicable if opposite sides of the street are not of the same elevation.

The subject of the form to be given to streets is discussed at much length and with reference to various cases in ‘‘Traite Pratique des Travaux en Asphalte,'' Letouze et Loyeau, Paris, 1897, and reference must be made to this work for more detailed formula and special applications.

Gutters.—In many cities where concrete curb and gutter are not in use, there has been a tendency to use either stone or brick as a substitute for an asphalt surface in gutters of asphalt streets. From what has been shown in the previous pages it is evident that where the asphalt-surface mixture is made on the lines laid down by the author, and where the form of construction employed in the street is such as to provide satisfactory drainage, there is no reason why the asphalt surface should not be carried from curb to curb, nor is there any necessity for painting such a surface with asphalt or bitumen, if the mixture of which it is composed is constructed on modern lines. In the early days of the industry this painting became the custom, owing to the fact that the mixtures were made with sand so badly graded and so porous that they could not resist water action.

CHAPTER XXIII.

THE MERITS OF THE MODERN SHEET-ASPHALT PAVEMENT.

WHETHER a sheet-asphalt pavement possesses any lasting degree of merit will depend entirely upon the manner in which it is constructed from the base up, including proper drainage and the character of the asphalt mixture which forms the surface. It has already been made evident that the greatest care is necessary in all these respects. It will be only worth while, therefore, to consider what the merits are of a sheet-asphalt pavement of standard construction. Such a pavement is desirable for the following reasons:

1. It does not disintegrate under impact or attrition, and consequently produces neither mud nor dust.
2. It can be kept perfectly clean if the proper efforts are made to do so.
3. It has an impervious surface and does not absorb filthy liquids, as is the case with wood blocks.
4. It affords the best foothold for horses except under occasional conditions.
5. Traction on such a surface can be carried on with a smaller expenditure of force than on any other form of pavement.
6. Its wearing properties compare more than favorably with granite and exceed that of any other form of pavement under heavy traffic.
7. Deterioration in a standard asphalt pavement is of a kind that can be readily and economically met owing to the simplicity of making repairs, something that cannot be done satisfactorily with any other form of pavement.

8. Cuts in the pavement for underground work can be replaced in a manner which makes the repairs undistinguishable from the original surface, whereas they are quite evident in the case of other pavements.

9. It increases the actual and rental value of all real estate abutting on streets where it is laid to a larger extent than any other form of pavement.

10. The wear and tear upon horses and carriages is largely reduced by asphalt pavements, and it has been estimated for Philadelphia [1] that the repairs to vehicles in that city due to rough pavements existing there in 1885, which could be saved by sheet-asphalt pavements, would amount to $1,000,000 annually. The universal testimony of fire-department chiefs is that there is far less wear and tear to the running gear of the engines, hose carriages and trucks on asphalt pavements than on stone blocks, and consequently less liability to break down or to have accidents, while much better time is made in going to fires.

That asphalt pavement will sustain the heaviest traffic that is carried by any street in the world can be seen from the following determination of the number of vehicles and the tonnage on Fifth Avenue and some other streets in New York City during the months of November and December, 1904. See table on page 457.

The heaviest traffic in London, as determined in 1879, was 422 tons per foot of width per day. The traffic on Fifth Avenue, which has been an extremely successful asphalt pavement, is, therefore, equal to, if not greater than, that sustained by the pavement on many of the most heavily travelled streets of Europe.

The defects which have generally been assigned to an asphalt pavement are its comparatively great first cost and cost of maintenance. Its first cost may be larger than that of some other inferior forms of pavement, but considering the length of time that an asphalt surface will wear, if of standard construction, this cost is smaller per annum and per ton of traffic carried than that of any other form. The cost of maintenance has no doubt been large for many pavements constructed in the past and will be large for many constructed in the future which are not of standard composition. With the best form of construction the cost per yard will not be excessive and the public will have the advantage, if the city maintains its streets, which unfortunately is not always the case, of having a perfect pavement at all periods of its existence, instead of one which becomes worse and worse with each year of its age.

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[1] The Philadelphia North American, Oct. 12, 1885.

Another defect has been said to be the fact that it is unsuited for steep grades. From the figures given on pages 450 and 451 it is evident that this is not so.

There can be no question that a standard sheet-asphalt pavement possesses more merits than any other, and fewer defects. It is undoubtedly the pavement of the present and of the future.

TRAFFIC RECORD TAKEN ON STREETS PAVED WITH ASPHALT IN NEW YORK, N. Y., NOVEMBER AND DECEMBER, 1904.

	Tonnage per 11 Hours.	Average Tonnage per Linear Foot of Width per 11 Hours.	Average Tonnage per Hour.	Average Number of Vehicles per 11 Hours.	Average Tonnage per Vehicle.
Fourth Street, from Wooster to West Broadway.......	9254.22	289.18	841.35	3394	2.73
Eighth Avenue, from 35th to 36th Streets..........	13024.52	296.02	1184.05	5720	2.28
Thirty-fourth Street, from Broadway to Seventh Av.	2176.60	89.22	197.86	1072	2.03
First Avenue, from 26th to 27th Streets............	19253.76	435.58	1750.34	6034	3.18
Fifth Avenue, from 33d to 34th Streets............	19274.47	481.85	1752.20	11787	1.64
Broadway, from 18th to 19th Streets................	7491.70	299.63	681.06	3817	1.97

The Cost of Asphalt Pavements.—No general statement can be made in regard to the cost of an asphalt pavement, as it is a function of too many variables; these variables can, however, be considered individually. They are:

1. Freight rates for the transportation of the plant and materials of construction to the locality where the pavement is to be laid.

2. Local cost of materials of construction, such as sand, cement, gravel, broken stone, and filler.

3. The cost of local labor.

4. The form of construction which is specified.

5. The character of the traffic which the street is to carry, its grade, and the character of the pavement on adjoining streets.

6. The period of guarantee demanded.

7. The terms of payment.

With so many changeable conditions it would, of course, be impossible to give any general data as to the cost of an asphalt pavement. It may vary from $4 or $5 per yard on a street of extreme traffic in a large city which is guaranteed for 15 years, and $1.25 per yard on old brick pavement for the base where the traffic is very light, as in a residence street or where no guarantee is demanded, as is the case in the State of California.

Cost of Maintenance.—The cost of maintenance is quite as uncertain an element as the cost of construction; and even more so, since it will depend not only on the character of the original work but upon the amount of attention which is given by the company constructing the pavement, or by the authorities after the former's guarantee has expired, to keeping the surface in first-class condition. If it is neglected the cost of maintenance may become large, whereas if carefully kept up this may well be small.

The character of the base which supports the pavement will have more to do with the cost of its maintenance, if the surface is a standard one, than any other controlling condition. In the observation of the writer at least 90 per cent of all maintenance work on asphalt pavements with well-constructed surfaces is due to weakness and deficiency in the base.

It is of interest in this connection, however, to note the data contained in a paper by Capt. H. C. Newcomer, Corps of Engineers, United States Army, in regard to the cost of maintenance of the asphalt pavement in Washington, D. C., especially as the surface mixtures laid in that city have been, unfortunately, not of standard quality, owing to deficiencies in the character of the local sand supply. Capt. Newcomer has found [1] that "the average cost per square yard per annum for the second five-year period of the life of the pavements considered was 1.65 cents; for the third five-year period, 3.37 cents; for the fourth five-year period, 3.78 cents, and for the fifth five-year period, 2.56 cents. The average cost for all ages tabulated was 2.8 cents."

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[1] Engineering News, 1904, Feb. 18, **51**, 165.

It is worthy of note in this connection that of the 2,425,732 square yards of bituminous pavements of all kinds, including coal-tar, in the preceding estimate, many of which were very inferior, not less than 2,161,181 square yards were constructed of Trinidad asphalt.

CHAPTER XXIV.

ACTION OF WATER ON ASPHALT PAVEMENTS.

The action of water on asphalt and on asphalt pavements has been a prominent topic of discussion from the early days of the industry, and the subject, for many reasons, remains one of peculiar interest to-day, since many mistaken ideas in regard to it are still in vogue.

Asphalt surface mixtures, the mineral aggregate of which is not properly graded and balanced and which, in consequence, lack density and an impervious surface, are attacked by water when subjected to its continued action, from lack of proper drainage or other reasons, without regard to the nature of the asphalt of which the mixture is made, although under these conditions one asphalt may be attacked more than another. With the standard surface mixture constructed on the ideas laid down by the author in the previous pages surface mixtures may be constructed of any asphalt which are equally resistant to water action, but all of which are attacked more or less by the water unless allowed to dry out at intervals. In a properly constructed pavement no important deterioration from water action should ensue within the life of the pavement and, as a matter of fact, in the author's experience, the deterioration in the asphalt surfaces laid under his supervision has in the last ten years become an item which is hardly worth consideration, where the form of construction has provided satisfactory drainage.

As it must be admitted that asphalts are attacked by water to different degrees when the mixtures are not dense, and especially in laboratory tests, it is of interest to examine into the reason for this, in order that we may be able to compare practical results with those obtained by experiment and determine the means for preventing such action on pavements actually in use.

Numerous observers have detected and noted the fact that there is a difference in the degree to which water acts upon various asphalts and fluxes. Messrs. Whipple and Jackson have made an elaborate investigation of the subject, the results of which were presented in a paper read before the Brooklyn Engineers' Club in March, 1900, which was published in the Engineering News for March 22, 1900. These results, although of little interest as showing the effect of water on a well-constructed asphalt paving mixture, since the pure bitumens were themselves exposed by these investigators directly to the continued action of water in order to determine their relative value for the construction of concrete lining for reservoirs and not for pavements, are of interest as showing that experiments conducted under conditions employed by these investigators may lead to conclusions which are utterly erroneous as applied to the paving industry, except when the asphalts in question are used in an unskillful way.

Actual Results on the Streets.—It is of interest to consider what the practical experience has been on the street during the last fifteen years as regards the action of water on asphalt surface mixtures. In the early days of the industry, as has already appeared, the asphalt surface mixtures were very open. At the time that the author was connected with the Engineer Department of the District of Columbia the Trinidad asphalt surface mixtures were constructed with coarse sand and very little filler. The gutters of streets which were paved with mixtures of this description were much given to deterioration from the action of water, and the same conditions were met in other cities, so that at that time every one believed that it would be impossible to construct a Trinidad surface mixture which would not be attacked by water. This idea has persisted in the minds of many who have not followed the industry carefully down to the present day, and it was only dissipated in the author's mind by an experience extending from 1894 to 1896 during an attempt to introduce the American form of asphalt pavement in London, England. In 1894 a Trinidad asphalt surface was constructed on Pelham Street, Kensington, and on King's Highway, Chelsea, in London, using Trinidad asphalt in much the same way that he had employed it in previous years in Washington, D. C., the modern methods of constructing a mixture to withstand heavy traffic and wet climate not having been developed at that time. The results were that the pavements were not an entire success and scaled. It was suggested that this was due to the fact that the asphalt in use was Trinidad and that this was constantly attacked by the continuous fogs of London. The pavements were, therefore, replaced in the following year with a mixture made with Bermudez asphalt. These surfaces went to pieces much more rapidly than the previous Trinidad surfaces. By this time the principles which have been elucidated in the preceding pages had been largely worked out. In the third year Trinidad asphalt surfaces were laid in London on these lines which not only were not attacked by the continued wet weather and fogs of that climate, but which have remained there to the present time, having shown no deterioration due to water action. If the Bermudez surfaces had been constructed with the same regard to the mineral aggregate and to the character of the asphalt cement prepared from it they would undoubtedly have shown an equal freedom from the action of water, but it is not probable that they would have shown an equal resistance to the deteriorating influence of the heavy traffic on the streets on which the pavements were laid. Practical experience rather than theory, therefore, leads the author to conclude that an asphalt which may not appear to be as satisfactory in laboratory tests may prove more so in actual construction.

That asphalts which are not attacked by water in the laboratory may be seriously affected by it in asphalt surface mixture has frequently been revealed, but never in a more striking way than in Reading, Pa., where house drainage is conducted along the gutters of the Bermudez asphalt pavements of that town, in consequence of which they have entirely disintegrated, as shown in the accompanying illustration, Fig. 27.

It appears then that it is the manner in which the asphalt is used and the practical results obtained with it rather than its

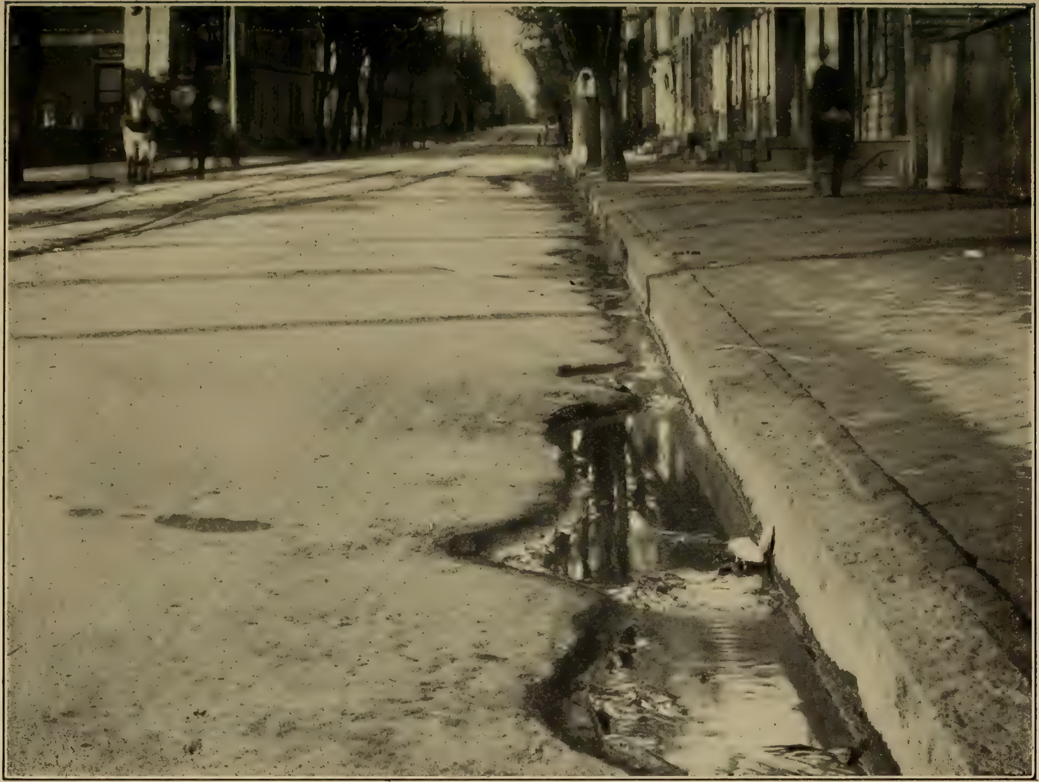

Fig. 27.—Bermudez Asphalt Surface Disintegrated by Water.

properties as revealed by laboratory tests which should control our judgment in forming an opinion of its behavior towards water in an asphalt-surface mixture on the street.[1]

As a practical example of the difference between surface mixtures actually in use and made with different asphalts in their relation to water absorption in the laboratory, the results of an examination of the Trinidad and Bermudez surface mixtures which were being laid in the city of New York in the year 1904 may be of interest. These mixtures consisted of the following materials in the proportions given and had the following composition:

Proportions.	Trinidad.	Bermudez.
Sand (1 Cow Bay and 1 Crossman)	74.7%	73.7%
Filler (P. C. dust)	9.6	14.8
Asphalt cement	15.7	11.5
	100.0	100.0
Analyses.		
Bitumen	11.0%	11.2%
Passing 200-mesh sieve	16.0	17.8
" 100- " "	11.0	12.0
" 80- " "	11.0	10.0
" 50- " "	24.0	27.0
" 40- " "	13.0	12.0
" 30- " "	7.0	5.0
" 20- " "	4.0	3.0
" 10- " "	3.0	2.0
	100.0	100.0

Of the above mixtures cylinders 1 inch in height were made having the greatest density possible, by compressing them under impact in a diamond mortar of a diameter of 1.25 inches. The cylinders of mixtures had the following densities and weight:

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[1] This subject has been discussed at length in the Engineering News, 1904, June 2, 51, 520.

Cylinder Number.	Trinidad.		Bermudez.	
	Density.	Weight (Grams).	Density.	Weight (Grams).
1.......	2.247	47.522	2.262	46.728
2.......	2.200	47.227	2.225	47.410
3.......	2.204	46.963	2.232	47.551
4.......	2.217	46.885	2.277	49.631
5.......	2.214	48.536	2.222	49.410
6.......	2.223	49.548	2.260	52.257
Average.	2.217	47.780	2.246	48.831

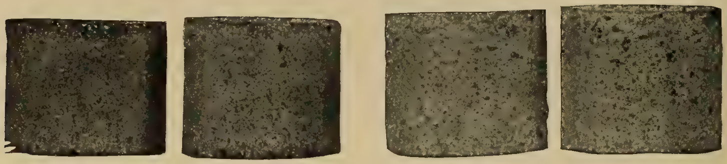
These cylinders were exposed to the action of running water for a length of time. The gain in weight of the cylinders at various intervals is shown in the following table in fractions of a pound per square yard:

ABSORPTION OF WATER. POUNDS PER SQUARE YARD.

Cylinder Number.	Trinidad.				Bermudez.			
	1 Week	4 Weeks.	2 Months.	3 Months.	1 Week.	4 Weeks.	2 Months.	3 Months
1.......	.0849	.1111	.1262	.1291	.0961	.1020	.1183	.1174
2.......	0789	.1009	.1190	.1194	.1485	.1428	.1640	.1694
3.......	.0763	.0991	.1149	.1171	.0868	.0914	.1134	.1103
4.......	.0869	.1069	.1199	.1240	.0894	.0883	.1077	.1089
5.......	.0839	.1066	.1237	.1254	.0909	.0966	.1198	.1194
6.......	.0706	.0943	.1137	.0914	.0526	.0566	.0746	.0729
Average.	.0803	.1031	.1196	.1177	.0940	.0963	.1163	.1164

After an exposure of three months none of the cylinders showed any signs of softening. Those containing Bermudez asphalt could, however, be distinguished from those made with Trinidad asphalt by slight excrescences the size of pin-heads, which had appeared upon the surface. Fig. 28. It must be remembered, too, that the cylinders were not prepared from mixtures made in the laboratory, but were made from material which was actually being used on the street.

When pieces of glass were coated with Trinidad and Bermudez asphalt cement and with one made from a California residual pitch and immersed in running water for a week they were all more or less attacked thereby, as can be seen from the accompanying illustration, Fig. 29. From the preceding results it is apparent at once that although all asphalts under certain circumstances are attacked by water, Trinidad asphalt when properly used in an asphalt surface mixture is the equal of any other in resisting power, and this fact being proved to a contractor's satisfaction, he

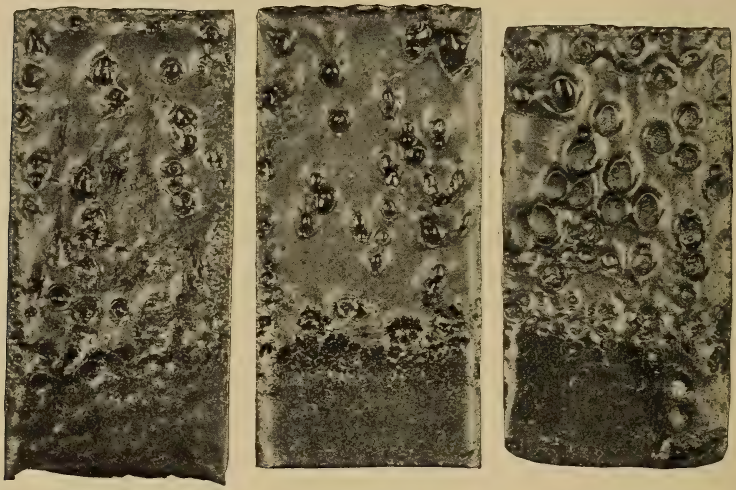


Trinidad Lake Asphalt. Bermudez Asphalt.

Surface Mixture.

In running water five months.

Fig. 28.



California Oil Asphalt Cement. Bermudez Asphalt Cement. Trinidad Lake Asphalt Cement.

In running water one week.

Fig. 29.

prefers to employ it for the many reasons which have been given in another place, namely, because no other material offers such a uniform supply as that taken from the Trinidad pitch lake, every cargo being handled in the same manner as those preceding it, because the bitumen which it contains is free from hydrocarbons, which are volatile at the temperature at which it is necessary to maintain a surface mixture, in consequence of which asphalt cement made with it from proper flux is peculiarly non-volatile and non-changeable at this temperature, and because it can be maintained for a considerable length of time at high temperatures without hardening excessively, even when tossed about loosely with excessively hot sand in any process of turning out the surface mixture.

Cause of the Action of Water on Asphalt Under Certain Circumstances.—All bitumens, as has been seen, are more or less acted upon by water under certain conditions. It is a matter of great interest to determine what conditions are most favorable for the destructive action of water, how far this action is inherent in certain properties of the bitumen, and how far to the presence of gases or salts soluble in water, or of the latter mixed with the asphalt.

There has been a great cry that the soluble salts in Trinidad asphalt were the cause of the deterioration of this material in the presence of water. The idea unfortunately originated with the author many years ago on insufficient evidence. It was soon shown that the addition of 5 per cent of common salt to a Trinidad asphalt surface mixture or immersion of the latter in salt water completely prevented any disintegration, even of the old-time open surface mixture. This, of course, quite does away with the idea that the presence of soluble salts in Trinidad asphalt has anything to do with its disintegration when exposed in the refined condition to the continued action of water. As a matter of fact, the bitumen of Trinidad asphalt is not in itself attacked by sea-water under the conditions imposed by Messrs. Whipple and Jackson.

When the material which has become disintegrated and brown under these tests is remelted the original bitumen is recovered in an unchanged condition, both as to consistency and softening point. The action of the water seems, therefore, to be in this case caused by its absorption by some of the organic matter or non-bituminous matter which the asphalt contains. If the vegetable matter is so sealed up in the asphalt or in the surface mixture as to prevent diffusion no disintegration occurs. As a preventive against the slightest diffusion the presence of a material, such as Portland cement, which will combine with the water is desirable.[1]

That asphalt surfaces can be constructed from any asphalt so that they will not be attacked by water has been conclusively proved within the last few years. In the same way it has been equally conclusively proved that all asphalts, under certain conditions, are more or less attacked by water.

That a distinct advance has been made along this line can be seen by comparing the amount of water absorbed by the surfaces of 1894 as compared with those of ten years later, as shown in the following table:

ABSORPTION OF WATER BY CYLINDERS OF ASPHALT SURFACE. IN POUNDS PER SQUARE YARD.

	Washington, 1893.		Standard Mixture, 1904.	
	Trinidad.	Bermudez.	Trinidad.	Bermudez.
7 days..	.314	.063	.080	.094
14 " ..	.434	.194	.093	.093
28 " ..	.502	.306	.107	.104

The conditions to which asphalt surface mixtures are subjected in the street and in the laboratory bear no relation to one another. In the ordinary laboratory tests surface mixtures are submitted to the continued action of water, except when burnished from time to time with a burnishing-tool for experimental purposes, and receive no compaction as does the street surface from the traffic which it receives. In the street an asphalt surface is never subjected, at least in well constructed pavements, to the continued action of water. The conditions are, therefore, in this respect very different from any which are found in laboratory experiments. The conclusion must, therefore, be drawn that we must be guided in forming an opinion in regard to the availability of any material by the results obtained in practice and not by theoretical deductions from laboratory experiments. The asphalt surface laid on Fifth Avenue, New York, a thoroughly well-constructed surface, if the presence of an open binder is barred, has been practically unacted upon by water, although made of Trinidad asphalt, in the ten years of its existence, since no repairs of any amount have been made to the pavement due to deterioration of the mixture. No doubt a very small amount of deterioration may be detected in the gutters along the curb, but this would have been the same in the case of other asphalts as in the Trinidad mixture and does not reach an extent to demand consideration.

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[1] See page 27: P. C. as a Filler.

In this connection it is of interest to call attention to the fact that a process has been patented for washing crude Trinidad asphalt for the removal of soluble salts before it is refined, and that it is true that material thus treated withstands laboratory tests to a somewhat better degree than the untreated material when exposed to the action of water in the refined condition, but the behavior of the surface mixture is not improved by it to any appreciable extent, and the process must, therefore, be regarded as involving an additional expense with no compensating return.

In conclusion the author may state with the utmost conviction that no Trinidad asphalt pavements which have been laid under his direction in the last ten years have suffered from the attack of water when a proper form of construction has been employed. All attempts which have been and are now being made to prove the contrary are based purely upon personal and political attempts to disparage the nature of the material.

SUMMARY.

An endeavor is made in the preceding chapter to show that the conclusions derived from laboratory experiments and from the results of poor workmanship, as regards the action of water on asphalt surfaces, are not practical, but merely theoretical. It is shown that with requisite skill, surface mixture can be made from those asphalts which are themselves attacked by water in the refined state in the laboratory which will not be at all attacked by water either in the laboratory or on the street. Statements to the contrary generally originate in a desire to damage the reputation of a material for reasons arising in business rivalry.

PART VIII.

CAUSES OF THE DEFECTS IN AND THE DETERIORATION OF ASPHALT SURFACES.

CHAPTER XXV.

DEFECTS IN AND DETERIORATION OF ASPHALT PAVEMENTS.

Asphalt surfaces, like all pavements, necessarily deteriorate with age even when they are originally of the most acceptable form of construction. When they are not well constructed they deteriorate very rapidly.

Defects in asphalt surfaces are more apparent than in any other form of pavement, since it is a continuous, smooth surface without joints. The eye, as well as the effect of any irregularity upon the vehicle passing over it, reveals them at once, where the difference between a perfect and worn stone or brick surface is not as noticeable.

The proper method of construction of an asphalt pavement and the characteristics of a desirable asphalt surface mixture have already been elaborated. At this point it seems appropriate to sum up the causes of the deterioration in such surfaces which are due to defects in construction or environment and to follow this with an examination of the causes of legitimate wear.

Deterioration of or defects in asphalt pavements are attributed to three principal causes and many minor ones:

1. Defects in construction due to
   - A. Improper specifications or form of construction.
   - B. Lack of lateral support.
   - C. Inferiority of sand, in the character of the filler or lack of a sufficient amount of it.
   - D. Inferiority in the asphalt or lack of intelligence in its use.
   - E. Careless workmanship and ignorance.
2. Unfavorable environment.
   - A. Climate.
   - B. Lack of cleanliness and general neglect.
   - C. Action of water, of illuminating-gas, or of gas and water combined.
   - D. Flushing with water under pressure.
   - E. Constant opening of the surface for underground work.
3. Age.
   - A. Natural wear.
   - B. Neglect of maintenance.

Improper Specifications.—It often happens that from motives of economy specifications provide for a form of construction of asphalt pavements which is deficient in one or more respects from what is necessary to enable them to meet the conditions to which they are to be exposed.

Particular attention has already been drawn to faulty provisions for a suitable foundation and for proper drainage. It is hardly necessary to recur again to this matter here except to emphasize the fact that without a rigid foundation and proper protection of the surface mixture from water reaching it from the bottom, or standing on or flowing constantly over the top, an asphalt pavement in every other way of the highest type of construction cannot have a long life, at least without extensive maintenance.

Specifications are also at fault in regard to the depth of the binder course required. An inch of binder made of inch stone cannot, in the writer's opinion, form a sufficient bond to keep it from going to pieces under constant traffic, especially if it is supported by only a weak base. It is probable that on the heaviest travelled streets in our large cities an open binder course is an unsatisfactory form of construction. In summer when the surface is soft the binder is crushed under the weight of trucks with too narrow tires, carrying loads of as much as seven tons, particularly when the binder stone is not hard. The binder in such cases should be replaced by a denser mixture, one in which the voids in the stone are filled by a bituminous mortar, in fact, the regular asphaltic surface mixture. Such an asphaltic concrete supports the surface, most satisfactorily distributes the load over the base, and is of great advantage when placed over a base subject to vibration, such as stone blocks which have been reset, or laterally against a vibrating rail. Specifications for such a course have already been given.

The thickness of surface specified is less often at fault. If properly supported, an inch and a half of surface made of desirable constituents has satisfactorily carried heavy traffic. A greater thickness may often be preferable for business streets, but the greater the thickness the greater the difficulty in raking out the hot mixture evenly and obtaining uniform compaction and the greater its liability to displacement with the formation of waves or inequalities in the surface.

A very frequent fault in specifications for asphalt pavements is that it is provided that the street should be constructed without sufficient crown. The only objection that can be raised against a high crown is that the pavement is slippery on the quarters, but this is a very small objection compared to the fact that flat streets are unsightly because it is impossible to so grade them as to throw off all the water and because where water stands in this way it cannot but have an undesirable effect upon the surface. The height of a crown which a pavement should have has already been considered.[1] It may be added that defects due to lack of crown are more emphasized in careless work than when the pavement is laid with skilled labor and supervision.

Lack of Lateral Support.—Attention has been called to the fact that a sufficient lateral support, free from vibration, is as essential as a rigid foundation. An asphaltic surface cannot be expected not to deteriorate against a rail which vibrates or against a header which is not rigid, where the asphalt joins some other form of roadway.

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[1] See page 451.

Proper provision for avoiding deterioration from these causes is rarely made and should receive more attention. Along a rail which shows the least tendency to vibration, paving brick in three or four rows, all laid as stretchers with broken joints in Portland-cement mortar, experience has shown is by far the most advantageous form of construction, or, if the asphalt surface must be carried to the rail, it should be supported on an asphalt concrete and not a binder.

Inferiority of Available Sand.—The important rôle which sand plays in the construction of an asphalt surface and the great variations which are met with in the character of this material have been made plain in preceding pages. It is evident that the sands available in one city may be far inferior to those found in another, but this demands only the more care in selecting the best and using them with the greatest skill. In two western cities it is only after seventeen years' experience and search for sand that the proper supply has been found. The great improvement brought about in the character of the surface mixtures now laid in these cities by the use of the sand finally selected is most evident and satisfactory. The result points out the great advantage derived from a thorough knowledge of the characteristics of various sands and by having in charge of securing supplies superintendents who are thoroughly acquainted with the subject. Where the superintendents are incompetent and do not pay sufficient attention to their sand, the surface mixtures which they produce are inferior. This is illustrated by the mixtures laid by six companies in the city of New York in 1904, the grading of which is given on the following page in comparison with that produced under the author's supervision.

It will be noted in the table that the mixture turned out under the author's supervision in 1904 is not up to the standard. This is due to the fact that the available sand supply in that year was unsatisfactory. The other mixtures are, however, much more unsatisfactory, and, although they contain in all cases a sufficient amount of bitumen, they are very deficient in sand grains passing the 100- and 80-mesh sieves and generally contain far too much coarse material of 10-, 20-, and 30-mesh size. Such mixtures, on this account, cannot result in a sur-

AVERAGE COMPOSITION OF MIXTURES PRODUCED IN NEW YORK CITY IN 1904 WITHOUT PROPER SUPERVISION OF THE GRADING.

Company No.	Bitumen.	Passing Mesh.								Retained on 10.
		200	100	80	50	40	30	20	10	
1.....	11.0%	9.0	3	7	17	20	13	12	8	
2.....	11.3	10.7	5	4	18	11	11	14	13	2
3.....	10.4	9.6	5	7	18	14	13	12	10	1
4.....	11.8	12.2	8	6	20	12	14	11	5	
5.....	10.7	6.3	5	5	24	18	13	10	7	1
6.....	10.8	8.2	4	3	15	12	15	11	13	8
7[1]....	10.9	14.1	11	10	28	13	7	4	2	

[1] Author's mixture, 1904.

face which will be impervious to water. It will also be noted that the percentage of 200-mesh material is lower than in that which the author supervises, although in two instances it is above 10 per cent, in two others over 9 per cent. It must be borne in mind in this connection that the sand in use contains a very considerable percentage of 200-mesh material, often 6 to 9 per cent. This material is largely sand and does not act as a filler, so that the deficiency in the above mixtures does not seem as large as it really is, but they are all of them actually deficient in filler. In the case of companies 5 and 6 the deficiency is very large, and these mixtures may be pronounced very inferior on this account and because this deficiency is accompanied by a similar one in fine sand and by the presence of a very large amount of coarse material.

In other cities mixtures have been laid which show even greater deficiencies, and illustrate very well the inferior character of the material which is turned out without a thorough understanding of the principles underlying the production of a standard surface mixture, and without proper laboratory control. Had the latter been exercised, the defects in these mixtures would have become apparent before the material was laid. See table on page 476.

More gross defects in pavements are due to the improper use of sand than to any other causes except too hard bitumen or weak foundation.

City.	Bitumen.	Passing Mesh.								Retained on 10.
		200	100	80	50	40	30	20	10	
Buffalo, N. Y.	9.2%	4.8	12	19	53	2	0	0	0	
“ “	10.6	8.4	4	8	31	5	3	5	9	16
Chicago, Ill.	8.8	16.2	16	30	22	2	2	1	2	
“ “	11.3	6.7	4	6	45	15	9	1	2	
“ “	9.9	4.1	4	27	42	5	4	2	1	1
Cedar Rapids, Iowa	9.9	9.1	5	12	44	10	5	3	2	
Erie, Pa.	9.3	7.7	3	8	45	11	6	5	5	
Long Island City, N. Y.	10.6	6.4	6	7	35	15	9	5	6	
Louisville, Ky.	9.9	12.1	18	30	28	2	0	0	0	
Newark, N. J.	11.1	4.9	10	14	33	10	11	2	2	2
New Orleans, La.	8.7	8.3	3	4	32	26	12	4	2	
“ “ “	9.5	11.5	4	5	32	23	11	3	1	
Omaha, Neb.	9.0	5.0	11	12	27	15	12	5	4	
Pittsburg, Pa.	12.7	5.3	8	5	53	8	4	2	2	
Toronto, Ont.	9.8	5.2	10	14	35	14	6	4	2	

It may happen, of course, that in some places the highest grade of asphalt-surface cannot be laid with the available sand supplies and that their lasting or wearing properties in such cities must, therefore, be inferior to those which can be laid in others with more suitable sand.

Character of the Filler.—As has been shown [1] the character of the filler in use in asphalt-surface mixtures is very variable. If it is coarse and used in insufficient amount the result will be a decidedly inferior mixture. As an example of this, certain streets are known to the author, which were laid in the downtown section of New York in 1895, with an asphalt surface mixture containing no filler. These streets rapidly lost their shape through displacement of the surface or lack of stability in the mixture, and they have long since been resurfaced.

It can be seen, therefore, that deterioration of asphalt pavements may at times be attributed to the lack of filler, to its poor character or to its unintelligent use.

On street surfaces which are to be subjected to the heaviest travel the use of Portland cement as a filler has been found to well repay the extra expense incurred.

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[1] See page 89.

Inferiority in the Asphalt or Lack of Intelligence in its Use.—Defects due to the character of the asphalt in use and lack of intelligence in handling it are and have been the most frequent in pavements laid by inexperienced or unintelligent persons. By a proper combination of different native bitumens of different properties an asphalt cement can be made in which more or less of any available kind may form a part, but certain bitumens require much more skill in handling, while others will stand much greater abuse. Trinidad lake asphalt has been shown to be of the latter class, while others, either deficient in hydrocarbons of the malthene group, or containing light oils volatile at high temperatures or unsaturated hydrocarbons which readily become altered in their state of molecular aggregation and consequently in their consistency, are of the class which require skill and care in their manipulation. Others again necessitate the use of particular fluxing agents and result in comparative failures when improper ones are used. These differences have been taken up in the description of the properties of the several native bitumens.

Asphalt cements made in this way with a flux which is unsuitable for the purpose may thus be the cause of failure or deterioration. Such a cement may contain an excess of paraffine scale, of light oils, of cracked products, or of unsaturated hydrocarbons, which are rapidly converted to pitch on heating. Defects in asphalt surfaces have been due frequently to such reasons in the past. They are not as frequent to-day, but public officials cannot be too careful in determining the quality of the flux in use in preparing the asphalt cement with which a surface for which they are responsible is laid. Large numbers of Bermudez asphalt pavements laid between 1894 and 1900 were failures because the asphalt cement of which they were made was not handled with skill.

Careless Workmanship.—Poor workmanship may be due to either ignorance or intention, and unfortunately it is too often due to both combined. The careless and irresponsible contractor who looks to immediate profits, who has little experience in the cost of maintenance of pavements, who does not set aside a certain amount of money for this purpose or consider it in his bid for construction, is doing more to discredit asphalt pavements to-day than any inherent defects in the pavement, except perhaps the public officials who will not maintain their asphalt pavements after the expiration of the guarantee period.

Aside from the defects due to the nature of the asphalt, to the use of improper sand and the careless regulation of the mineral aggregate, others are attributable to asphalt cement made, as has been shown, with an unsatisfactory flux, or to the fact that it is too hard or too soft, irregular in amount or hardened, burned as the saying is, by too hot sand. All lack of attention to precautions for avoiding such defects, which are known to be fatal to the production of the best surface mixture, may be set down, largely, to carelessness as well as ignorance.

Ignorance or lack of technical knowledge on the part of the contractor can be readily learned by inquiry as to whether the requisite technical supervision is exercised over his work by laboratory methods. A high-grade surface, it has been shown, cannot be laid without such a supervision of all the elements entering into its construction.

Intentional neglect of the proper construction from motives of economy can be detected by public officials if they are sufficiently acquainted with the technology of the industry. Unfortunately City Engineers are usually themselves insufficiently informed to do so, and it is for the purpose of instructing them that this book has been written. They must, as a rule, depute any inspection to subordinates, who are even less well informed, who quibble over small details and miss the important points, or to experts, men of no wide practical experience but rather theorists, with one theory one year, another the next, abandoning an old one for the novelty of the new, but not founding any of them on more than closet work and experiment, and failing to look back and draw conclusions of weight from practical results.

The asphalt surfaces which are laid to-day on a rational basis, under the writer's supervision, are built on no theory but by determining from a study of the composition of actual surfaces which have given the greatest satisfaction what a desirable form of construction is. The manner of working out this problem has been elaborated in previous pages.

Public officials are advised in determining the character of the work which is being done by any contractor who employs no scientific supervision of his process to note:

The number of barrels of cement and the amount of sand and stone used in a definite area of base.

The consistency of the asphaltic cement and its regularity, together with the character of the flux used in its preparation.

The character of the sand and its capacity for carrying bitumen and a proper amount of filler.

The grading of the mineral aggregate.

The regulation of the amount of bitumen in the surface mixture by means of the pat paper test.

The temperature of the materials.

The skill in handling the materials at the plant and on the street.

The Manner in Which Defects in Asphalt Surfaces Due to Faulty Construction are Manifested.—Defects in asphalt pavements due to the faulty methods of construction which have been described, are manifested in several ways.

The surface cracks, but does not disintegrate.

The surface cracks when the lateral support is weak and then goes to pieces under traffic.

The surface disintegrates in various parts of the roadway, forming depressions or holes extending to the base.

The surface, when wet, scales off in large thin patches.

The surface is displaced upon the base becoming wavy, high at one spot and below grade at another.

The surface is raised into waves by expansion of the hydraulic cement in the concrete base.

Cracking in asphalt surfaces have been found to be due to many different causes:

Induced by cracks in the hydraulic concrete forming the base.

Produced by too hard a bitumen in the surface mixture, or by one which is not sufficiently ductile at low temperatures.

Produced by too small a percentage of bitumen in the surface.

Produced by the use of an unsuitable bitumen.

Produced by an unsuitable mineral aggregate.

Produced by lack of compression.

Produced by lack of traffic.

Produced by sudden changes in temperature.

Produced by vibration of rails, manholes and valve-boxes.

Cracking of Asphalt Surfaces.—Cracks in the hydraulic concrete base are at times reproduced in asphalt surfaces, even when the latter are of the best quality. The causes of cracks in base of this description must be referred to defects in the cement of which it is made, some of them expanding or contracting for some years after their use. Cracks due to this cause may be directly across the street or run in zig-zag directions along the crown and elsewhere, as shown in the illustration, Fig. 1, where cracks in the surface have been cut out to show those in the base. This form of cracking occurs both with natural and Portland cement, and with the very best surface mixtures under traffic, as well as with inferior ones under no traffic.

If the cracked portions are renewed after the cement has attained volume constancy with age and the surface repaved, the cracks do not return. They are not a common form of defect in an asphalt surface.

Cracks of the second description, due to the use of asphalt cement which is too hard or which has become hardened by being mixed with too hot sand, or to this cause combined with others, are the form which is most commonly met with. They are frequent in the hard Bermudez pavements laid in the Central States in 1898 and 1899, where the work was done according to a formula suitable for the materials available in 1893, but which with changed conditions resulted in later years in an asphalt cement of great hardness. Intelligence or proper supervision would have detected the unsuitable consistency of the cement. The results indicate the danger of following a blind formula.

Such cracks are of course due to the fact that the hard asphalt is too brittle at low temperatures to yield to the contraction of the surface It fractures under the tensile stress imposed upon it.

An actual measurement of the contraction of an asphalt surface made by Mr. E. C. Wallace, formerly Chemist of the Warren-Scharf Asphalt Paving Company, outside the window of his laboratory during cold winter weather, has shown that above 32° F. it is less than the average contraction of steel, and below freezing greater. This contraction is about that of quartz, and as quartz or similar mineral matter forms nearly 90 per cent of the mixture such a contraction would be expected.

Determinations of the coefficient of expansion of various materials have been collected in the following tables from the literature of the subject, and a few determinations made by the writer are given for that of residuum and asphalt cements.

COEFFICIENTS OF LINEAR EXPANSION FOR 1° C.

Substance.	Temperature.	Coefficient.	Authority.
Quartz, mean	0°–100° C.	1,000,010.67	Benoit
“ “	0°–100° C.	1,000,011.80	Pulfrich
Steel	0°–100° C.	1,000,010.9	Benoit
Petroleum, 26° B.	0°–100° C.	1,000,095	Sharpless
“ “	100°–101° C.	1,000,147	“
Paraffine, hard	0°– 16° C.	1,000,106.6	Rodwell
“ “	16°– 38° C.	1,000,130.3	“
Beeswax	10°– 26° C.	1,000,230	Kopp
“	26°– 31° C.	1,000,312	“
Eastern petroleum:			
Residuum, 21° B.	14°– 27° C.	1,000,989	Richardson
“ “	23°– 38° C.	1,000,838.9	“
Bermudez asphalt cement			
100 asphalt, 20 residuum	6°– 20° C.	1,000,544	“
“ “ “ “	20°– 45° C.	1,000,302	“

The coefficient of expansion of petroleum residuum does not, like that of most oils, increase with rise in temperature, probably due to the presence of paraffine, which solidifies at low temperatures and contracts rapidly. The bitumen of asphalt and asphalt cements contracts or expands in the same way. These results at first seemed rather startling, but reference to the literature of the subject confirms them. A paper by Holde in Mittheilungen der König, Technische Versuchsstation, 1893, 45–68, shows that:

"The heavy viscous products of distillation or residues from crude petroleum of different origin, possessing a specific gravity of at least 0.908, do not show any marked difference in their expansions between +20° C. and 78° C. Their coefficient of expansion varies from 0.00070 to 0.00072. Those oils holding solid paraffine suspended at temperatures below +20° C. (as German oils) have a higher coefficient of expansion between 18° C. and 20° C., viz. 0.00075 and 0.00081, owing to the melting of the solid particles.

"The heavy liquid products of distillation, of specific gravities below 0.905, at +15° C. possess a higher coefficient of expansion between 20° C. and 78° C., viz. 0.00072 to 0.00076. The American and Scotch oils belong to this class.

"As to the completely fluid lubricating oils, their coefficients of expansion rise gradually in proportion to the increase of temperature."

In an asphalt surface one thousand feet long between −20° F. and 130° F., extremes of temperature that are met with by Omaha surfaces, the contraction of the sand alone, forming 90 per cent of the pavement, would amount to from .902 to .920 feet, or from 10 to 11 inches. The contraction of the bitumen need not be considered, as this either elongates under the stress, or fractures. As low as 26° F. the elongation of a bitumen of proper consistency has been shown by experiments, to be described later, to take place quite readily. The contraction need therefore be considered only for the temperature between 26° and −20°, 46° F. or 25° C. For such an interval it would amount to about .29 of a foot per 1000 feet, or about 1 inch in a Fifth Avenue, New York, block. It is not surprising, therefore, that with a hard cement rupture of the surface takes place, but rather that it does not always take place.

The above conclusions are based entirely on theoretical considerations. Mr. S. Whinery and Mr. E. C. Wallace, of the Warren-Scharf Asphalt Paving Company, made some actual determinations some years ago of the expansion of an asphalt surface mixture on a laboratory scale. The means of measurement were not more accurate than 1/1000 inch. Using only those observations where the difference of temperature was 20° F. or more, and the expansion or contraction, therefore, so considerable that it could be measured in this way with a fair degree of accuracy, they arrived at results which seem to be worthy of some confidence. There were four series of these observations, and the results are given in the following table.

COEFFICIENT OF EXPANSION BY HEAT OF SHEET ASPHALT PAVEMENT. FROM OBSERVATIONS MADE BY LABORATORY OF THE WARREN-SCHARF ASPHALT PAVING COMPANY.

Series.	No. of Observations Used.	Mean Coefficient of Expansion.
A...........	13	.0000135
B...........	17	.0000140
C...........	12	.0000139
D...........	9	.0000131

As the coefficient of expansion of structural steel is about .0000065, it is nearly correct to say that the coefficient of expansion of asphalt surface mixture as determined in this way is double that of steel.

These results are about half of that which is arrived at theoretically. What weight can be given to the results is somewhat doubtful, but they are quoted here for what they are worth.

Cracks which are due to the fact that the mixture is deficient in bitumen, in consequence of which the surface does not possess sufficient tensile strength, regardless of ductility, at low winter temperatures, are not as frequent as those due to a hard bitumen, since in such a mixture, disintegration with the formation of holes takes place, as a rule, before cracking.

Cracks may be caused by the use of an asphalt cement which is unsuitable for the purpose to which it is applied. It may be too susceptible to temperature changes, so that, even if made so soft that the surface marks badly under a summer sun, it may be brittle at zero.

Finally, an asphalt cement may so harden with age that it becomes brittle in the course of a few years. Coal-tar is an example of such a material.

Cracking may be caused even with the most satisfactory asphalt cement by an unsuitable sand or mineral aggregate. Sands are known and have been used, the surface of the grains of which are of such a nature that melted asphalt cement will not adhere to them in sufficient thickness, and the voids in which are so small as to prevent the mixture from holding enough bitumen to give the pavement ductility. The sands available in other cities, without appreciable difference from those in use elsewhere, produce a surface which never cracks, even under unfavorable conditions and inferior workmanship.

Too fine a mineral aggregate may be a disadvantage on streets of little or no traffic.

Lack of density in the surface also favors cracking, whether brought about by insufficient compaction when the surface is laid or subsequent lack of traffic.

Traffic and the lack of it play a large part in preventing or causing the cracking of pavements.

Traffic releases tension to a large degree in a cold asphalt surface and assists elongation of the bitumen, so that heavy-traffic streets do not crack as readily as those of light or no traffic, and oftener crack only in the gutters, if at all, while light-traffic streets crack entirely across the roadway.

Suburban streets, not benefited by traction, at least in certain cities, are much more liable to crack than those which have a medium traffic. This is particularly well illustrated in a Canadian city where surfaces with only 8 to 9 per cent of bitumen are free from cracks on the downtown streets but are a mass of cracks in the suburbs, the bitumen present not being sufficient to give any elasticity unless the tension produced by contraction is released by traffic.

Climate, of course, plays a large part in determining the frequency of cracks in asphalt surfaces. Mixtures of almost identical composition will fracture under the conditions met with in one city and not in another. In those cities in the Missouri valley where sudden changes in temperature reaching 60° in a few hours, from 40° above zero to 20° below, cracking frequently results, where the same changes occurring more slowly in more protected locations do no damage.

Cracking along rails and around boxes and manholes is due to lack of support and may occur with the best mixtures. The causes have been considered elsewhere.

In all of the causes of cracking which have been cited, except the last, laboratory investigations have thrown some light on the subject and the results obtained are of interest.

Strength of Asphalt Surfaces.—An asphalt surface having the least ductility and tensile strength will, of course, rupture most readily under the tensile stress produced by contraction due to a fall of temperature. The tensile or crushing strength of an asphalt surface is, of course, a function of the temperature being greater at low than high temperature. Following are illustrations:

FIFTH AVENUE, NEW YORK. LAID IN 1897.

	Temperature.		
	6° F.	38° F.	76° F.
Pounds per square inch:			
Tensile strength	880	568	300
Crushing "	4862	2836	1820

In considering the subject of cracked pavements our interest is entirely in the strength and ductility of the surfaces at low temperatures.

From a great many old surfaces, some of which had cracked and some of which were free from them, briquettes were made and broken at 6° F. Averages of these determinations for the cracked and good surfaces in two cities are as follows:

TENSILE STRENGTH IN POUNDS PER SQUARE INCH AT 6° F.

No. 1.

Cracked pavements	664 (6)
Good "	722 (2)

No. 2.

Cracked pavements	497 (2)
Good "	614 (6)

There is a striking difference in the strength of the cracked and the good pavements in both cities in favor of the latter.

It is of interest in this connection to know what peculiarities contribute to the strength of asphalt surfaces. Experiments have shown that the principal conditioning elements are:

- Asphalt Cement.
    - Character.
    - Consistency.
    - Amount.
- Filler.
    - Amount.
- Sand.
    - Grading.
- Density of the surface.

This subject was looked into to a considerable extent by the writer in 1894. Unfortunately this work was done with the old coarse Washington surface mixture. With the modern well graded New York material more satisfactory results would now be obtained. The experiments suffice, however, to bring out several points. Following are the available data. See table on page 487.

These results show that the character of the cementing material has a very decided influence on the crushing, and it would also be found to be the same on the tensile strength of the surfaces. This subject was thoroughly discussed by the writer in a letter in the Engineering News for June, 1894, and it need only be said here that the strongest mixture is not the best, without regard to the nature of the bitumen, but that, with a proper cement, weakness

EFFECT OF THE CHARACTER OF THE BITUMEN ON THE CRUSHING STRENGTH.

Crushing Strength of Mixtures of Coal-tar, Trinidad Lake and Land, Bermudez, and Pedernales Asphalt.

Pounds per Square Inch.

Mixture.	Density.	At 38° F.	At 77° F.
Coal-tar, 15%	2.16	3880	1254
" 10%	2.07	3845	2655
Land pitch cement, 15% or 10% bitumen	2.13	1813	761
Bermudez cement, 10% or 10% bitumen	2.10	1955	635
Pedernales asphalt, 10% or 10% bitumen	2.06	2125	550
Lake pitch cement, 15% or 10% bitumen	2.14	1375	548

Ten per cent of dust and Washington sand in all mixtures.

at low temperatures due to ductility or elongation is preferable to high strength; weakness due to lack of bitumen, on the contrary, is not.

EFFECT OF THE CONSISTENCY OF ASPHALT CEMENT ON STRENGTH OF SURFACES.

Washington Mixture, 1894, Pounds per Square Inch.

Softness.	Crushing Strength.		Shearing Strength.	
	36° F.	77° F.	36° F.	77° F.
Trinidad cement:				
Normal consistency	1703	680	2865	1425
Softer cement, 3 lbs. more oil	1610	682	2005	1873
Bermudez cement:				
Normal consistency	2416	741	3193	1528
Softer "	3028	602	2569	1876

These results show that a softer Trinidad cement makes a mixture which has, owing to its great ductility, a smaller crushing strength at 36° than the one made with a hard cement; but with Bermudez cement this is not the case, as this cementing material is more easily affected by a fall of temperature.

With a better sand grading, however, the above results might be somewhat modified.

EFFECT OF THE QUANTITY OF ASPHALT CEMENT ON STRENGTH OF SURFACES.

WASHINGTON MIXTURE, 1894, POUNDS PER SQUARE INCH.

Amount.	Crushing Strength.		Shearing Strength.	
	36° F.	77° F.	36° F.	77° F.
Trinidad cement:				
Normal 15%	1703	880	2865	1425
More cement 16.5%	2425	768	2882	2378
Bermudez cement:				
Normal 10%	2416	741	3193	1528
More cement 11%	2544	961	2511	1636

These results show that an increase in the amount of asphalt in a mixture, up to a certain point, increases the strength of a Trinidad mixture in all cases; but, as before, not always, with Bermudez asphalt due to differences in the physical properties of the two bitumens at low temperatures.

EFFECT OF INCREASE OF AMOUNT OF DUST IN SURFACE MIXTURES ON THEIR TENSILE STRENGTH.

POUNDS PER SQUARE INCH.

Dust per Cent.	Trinidad at 36° F.	Bermudez at 36° F.	Trinidad at 77° F.	Bermudez at 77° F.
7.5	501	449	188	111
10.0	604	611	205	171
15.0	646	662	273	186
20.0	701	857	270	192

The addition of increased amounts of dust gives decided evidence of improvement of the mixture in all cases, and shows the necessity of using plenty of filler.

EFFECT OF DENSITY ON STRENGTH OF SURFACES.

Compaction.	Tensile Strength at 40° F.	77° F.	90° F.	Density.
	Pounds Per Square Inch.			
Least dense	463	152	101	2.08
Densest	646	273	166	2.23

The above results show that there can be no doubt that the densest mixtures are the strongest, at least with the same mineral aggregate and a sufficient amount of bitumen.

EFFECT OF SAND GRADING ON STRENGTH OF SURFACES.
WASHINGTON AND NEW YORK.

Composition.	Bitumen.	Passing.							
		200	100	80	50	40	30	20	10
New York..	10.6	14.4	11.0	12.0	27.0	11.0	7.0	4.0	3.0
Washington.	10.5	9.7	3.2	5.4	22.3	20.5	13.2	7.8	7.4

TENSILE STRENGTH, POUNDS PER SQUARE INCH.

	At 38° F.	At 78° F.
New York................	568 lbs.	300 lbs.
Washington..............	604 "	205 "

The difference between the fine and coarse mixture at 36° F. is slightly in favor of the coarse; at 78° F. in favor of the fine.

It must be remembered, however, that in these tests there are a number of conditions beside the grading of the sand that enter into the problem, so that final conclusions can hardly be drawn from so few experiments.

As a whole the results of these physical tests throw considerable light on the peculiarities of mixtures of varying composition and give us some information as to why some crack and others do not.

The possibility of cracking in asphalt surfaces are seen to be large, and it is remarkable how well they have been overcome by intelligent study of the conditions that are to be met. There is still much to be learned in this direction. It is impossible, as yet, to say why cracking has never occurred in pavements, even when not laid with the greatest care, in one city, while they are of general occurrence in another where the greatest care is exercised. It must, of course, be due to peculiarities in the surface of the grains of the sands in use, and the relative degree of adhesion of asphalt to them.

Cracks are never known to heal. Experiments have shown that an asphalt contracts longitudinally, but expands vertically, so that cracks once formed increase in width every winter, not only for this reason but because they become filled with dirt.

Cracks may be merely unsightly or they may be the essential cause of subsequent disintegration.

Asphalt surfaces on suburban streets in some climates crack to a marked degree after about three years service; but if the surface mixture is a good one, no disintegration follows and the pavement continues to be satisfactory in every other respect for as long a period as if no cracks existed. If disintegration takes place in such cases it is due to inferiority in the character of the mixture. There need be no alarm if no disintegration sets in. If local prejudice against a very soft surface which marks excessively when first laid does not exist, cracks may be largely avoided by using a very soft asphalt cement in the surface. In a northwestern city, where no asphalt surface had ever been laid on a residence street without cracks appearing in a few years, this was avoided in some laid by the writer by using a cement of 90 to 100 penetration insead of one of 65, as had been previously the case. The surface marked up under traffic excessively, however, during the first summer and aroused much comment. Communities soon become accustomed to this and the marking in new surfaces is objected to no longer, as it is understood that the pavement will eventually be a superior one. In consequence, much of the cracking of asphalt surfaces can now be avoided if they are originally laid with sufficiently soft bitumen, and the reason for the ensuing marking is properly explained to the public.

Disintegration.—Disintegration of the surface in various parts with the formation of depressions or holes extending to the base is the commonest defect in asphalt surfaces. Many defects of this kind are attributable to faults of construction, but they may also be due to unfavorable environment with the best of surface mixtures. Altogether they may be summed up as:

Deteriorations or defects due to:

Weak foundation—an extremely common cause.

Inferior mixture.

Action of illuminating-gas.

Action of water.

Uneven thickness of surface and constant pounding on depressions in an unbalanced mixture.

Weak Foundation.—An asphalt surface cannot resist the impact of traffic if the foundation does not furnish adequate support. This, as has been reiterated many times in these pages, is one of the most serious causes of the deterioration of asphalt pavements in large cities and where they are subject to heavy traffic and moisture. Any vibration in the surface, especially under unfavorable surface conditions such as dirt and continued moisture, is extremely liable to result in deterioration of a poor mixture and will aid in destroying the best surface. A defect due to weak foundation may be manifest in many ways. The surface may merely break up and go to pieces, or it may at first merely separate into small individual masses which become rounded at their edges and form a collective group of almond-shaped patches, which eventually go to pieces with a resulting hole.

Inferior Mixture.—Disintegration due to inferior mixture has been too thoroughly discussed in previous pages to necessitate a recurrence to the reasons therefor. It is, of course, in careless work the chief cause of defects in asphalt surfaces, but too often disintegration is attributed to a poor mixture which is due entirely to other causes.

Action of Illuminating-gas.—The disintegrating effect of the action of illuminating-gas is a subject which has not been considered hitherto in these pages. The writer cannot do better than by allowing Mr. A. W. Dow, his successor in the Office of Inspector of Asphalt and Cements, in the District of Columbia, to speak of his experiences in Washington with this cause of deterioration of asphalt surfaces, as all that he says applies as well to other cities. He writes as follows in his report to the Engineer Commissioner of the District of Columbia, for the fiscal year ending June 30, 1899:

"*Disintegration of pavements from the absorption of illuminating-gas, escaping from leaky gas-pipes or mains under the pavement:* There are several streets in the city being ruined by this means, and it appears to be a common thing in all cities having gas. The pavements are affected in very much the same way as when disintegrated by coal-tar binder, except the fine cracks, running parallel with the street, make their appearance sometime before the pavement begins to crowd. Pieces of the surface mixture taken up smell very strongly of illuminating-gas, and in some cases the gas can be ignited by applying a match to the under surface when it has just been taken up. In nearly every case enough gas will be given off by heating a small piece of the affected pavement in a tube to have it flash by igniting.

"As it has been doubted by some that this disintegration is really due to illuminating-gas, I have made a most thorough investigation of the subject and believe have positively proven that gas is the cause. Samples of pavements were obtained from several affected spots, and in all cases I have been able to obtain from them a gas that exploded by passing an electric spark after mixing with air. The method employed to obtain the gas from samples of the surface mixture was by heating them under boiling water and collecting the gas given off in an inverted funnel. Those not acquainted with the properties of asphalts might suggest that heating any asphalt to this temperature might make it give off a gas. This is impossible, as an asphalt cement such as is used in paving will lose only 3 or 4 per cent at the most on being kept at a temperature of 400° F. for 30 hours, and only an infinitesimal part of this loss is a gas at ordinary temperatures. To make a more practical demonstration of this, two samples of a pavement were taken, one from an affected spot and the other from a good portion of the pavement about 10 feet away. These samples were treated under boiling water until they ceased to evolve gas. The affected sample gave several times more gas than did the other. On testing, the gas from the good sample was found to consist of oxygen and nitrogen, which was evidently just the air from the voids of the pavement. The gas from the affected piece gave on analysis:

Carbon dioxide	8.4%
Oxygen	10.8
Heavy hydrocarbons	13.4
Carbon monoxide	0.7
Hydrogen	6.6
Methane	2.0
Nitrogen	58.1

"Having now found that a gas is present in the pavement so affected, let us proceed to examine as to its source. It cannot be a natural gas or marsh-gas, for there is no analysis of such gases on record that contains appreciable amounts of heavy hydrocarbons, while the gas from the pavement is rich in these compounds. The same would also apply to sewer air or gas. The only remaining source is illuminating-gas, the analysis of which is here given:

Carbon dioxide	0.2%
Oxygen	0.0
Heavy hydrocarbons	12.1
Carbon monoxide	25.5
Hydrogen	39.2
Methane	23.0
Nitrogen	0.0

"On comparing the composition of the gas given off from the disintegrating pavement with the illuminating-gas it is seen that they are not at all similar in composition. At first glance it would not seem possible that the former gas could originate from the latter, but when the properties of asphalt are considered it is easily explained.

"Heavy hydrocarbons, to which class asphalts belong, are known to absorb other gaseous hydrocarbons; the heavier the gas the more affinity between it and the heavy hydrocarbons. Knowing this, the ingredients of the illuminating-gas that asphalt would have the greatest affinity for would be the heavy hydrocarbon gases, a slight affinity for the marsh-gas or methane, and no affinity for any of the other ingredients. If we examine the ingredients of the gas from the affected pavement, it will be found to consist of some carbon dioxide, air that was in the voids and cracks of the pavement, and the constituents of illuminating-gas with the heavy hydrocarbon gases very much in excess, which is what we would expect. To practically demonstrate that the above takes place when asphalt is in contact with illuminating-gas, I took two samples of gas from a tap in the laboratory. One was analyzed, while the other was kept for several weeks in a tube the interior of which was coated with asphalt cement such as is used in pavements, after which it was analyzed. The results of the two analyses are here given:

	Original Gas.	Gas after Asphalt Absorption.
Carbon dioxide	0.2%	0.1%
Oxygen	0.0	0.0
Heavy hydrocarbons	12.1	7.2
Carbon monoxide	25.5	27.3
Hydrogen	39.2	42.2
Methane	23.0	23.2
Nitrogen	0.0	0.0

"It is evident from this that the asphalt cement has absorbed over 5 per cent of the heavy hydrocarbon gases, a little methane, and practically nothing else.

"I have ascertained by experiment that one part by volume of asphalt cement will absorb forty-two parts of illuminating-gas in somewhat over a month. I have also practically shown that asphalt is much softened by asborbing gas, the ordinary asphalt cement becoming as soft as a thick maltha after being in an atmosphere of illuminating-gas for several months. As to the quantity of gas contained in the affected pavements this of course varies, but in one instance 1000 c.c. of pavement gave off 500 c.c. of gas.

"There is but one way to stop the disintegration of a pavement from this cause, and that is to stop the leak of gas; for it is useless to patch the pavement, as it will not be long before the patch disintegrates. I have known of cases where a pavement so affected was repaired and in fourteen months the patches were showing signs of disintegration."

The writer's investigations have in every respect confirmed the conclusions of Mr. Dow.

Water Action.—The action of water on poor and unsatisfactory asphalt surfaces has also been considered at length. Continued standing or running water will destroy the best asphalt surface, but such a defect is one which can be avoided by proper provision for the prevention of such conditions. The best surfaces will resist for years any reasonable water action. Unfortunately provisions for preventing such action are not always adequate either from the presence of a porous base, seepage from soil in terraces above the level of the base, or poorly arranged grades to the actual surface of the pavement, which permit water to stand in the gutters. These defects, not inherent in the pavement but merely in the mode of construction, can be readily provided against.

Of the results of the action of water reaching the asphalt through a porous base, Mr. A. W. Dow writes as follows:

" *Disintegration by Water Entering a Pavement by Oozing up Through the Base.*—I believe if more thorough investigation were made into the cause for the disintegrating of pavement, this would be found to be one of the most common, especially in small towns and cities where there are terraces or considerable lawns in front of houses. There have been a number of cases in this city where the water has entered a terrace or parking where they were above the grade of the street and worked its way up through the concrete base to the asphalt surface.

" This disintegration manifests itself differently, depending on the character of the pavement. If the asphalt surface is soft or the concrete smooth, the first defect noticed will be the tendency of the pavement to crowd in warm weather. This is due to the under portion of the surface mixture rotting, so to speak, thus destroying the cementing properties of the asphalt. The upper portion, although good, being deprived of the support of the affected mixture under it, will be crowded out by traffic. This crowding is assisted by the concrete base being smooth, and also the bond between the base and binder are destroyed by the moisture.

" In cases where the concrete base is rough and the surface mixture hard, the principal disintegration will take place in cold weather, nothing abnormal being noticed until the pavement begins a rapid crumbling away in the affected spots under traffic.

"On examining a section of asphalt surface disintegrating from this cause, especially where it has not been going on for too long a time, there will be found a layer of perfectly sound and good material at the surface of the pavement, while underneath the mixture will show evidence of being disintegrated by water—that is, the sand will appear clean and white in spots, as though there had been an insufficiency of asphalt cement to cover it. The concrete base under the affected pavement will generally be found damp or even wet. We have prevented the destruction of several pavements from this cause by the use of blind drains put in under the gutter next to the lawn or terrace, and even run herringbone under the pavement.

"This last cause for disintegration would, of course, not occur in a pavement constructed with an asphalt that was unacted on by water, but water soaking up through a concrete base might injure any pavement by freezing.

"It is always advisable where a pavement shows signs of disintegrating to examine into the cause in a most careful manner and not pass snap judgment. It seems only too easy for the majority of people, whether experienced or not, to place the blame for the failure of a pavement on the manufacturers. I have heard men with considerable experience, commenting on a bad place in a pavement that they had not carefully examined, remark, 'They used bad oil or asphalt in that piece of work.' They have not taken into consideration that all but possibly a square yard of the pavement is in good condition and that it would be no economy to a contractor to use bad material in one small place of the pavement. A careful examination into the disintegrating of a pavement may, in many cases, show a cause that is entirely foreign to the composition of the materials and a cause that could be easily remedied with a little common sense."

The conclusions of Mr. Dow in regard to such causes of disintegration are most reasonable.

Poor Workmanship.—The raking of the hot asphalt mixture to an uneven thickness before compression, resulting in the formation of depressions in the surface under the final compression obtained from traffic results in disintegration of the less satisfactory mixtures owing to the constant impact of the wheels of vehicles suddenly dropping into such depressions. This is a fault often due to carelessness in construction and is not a common one.

Scaling of Asphalt Surfaces.—Scaling of asphalt surfaces has been in individual cases a serious cause of the deterioration. It is something which happens only in moist climates, particularly in those near the seacoast, or where fogs are prevalent, and where it is the custom to water streets continually without the removal of the accumulated dirt. It is particularly frequent with coarse mixtures, and in order to avoid it the grading of the sand, the character of the filler, the character of the asphalt and flux in use, their proper combination, together with the support of the resulting surface on a base free from vibration, must receive the most careful attention.

That the problem can be successfully met has been proved by the fact that pavements which have not suffered from scaling have been laid on Broadway and Fifth Avenue in New York, and in the foggy and damp climates of London, Glasgow, and Paris, in the first of which cities the successful application of the modern asphalt surface mixture was worked out in 1896 after two failures, to be equally successfully followed by similar results later in Glasgow and Paris.

Scaling is characterized by the separation under traffic, when the streets are wet and the air so humid as to prevent their drying, of a thin film of the asphalt mixture from the surface of the pavement. No satisfactory explanation of this phenomena has been advanced. We must content ourselves with noting its occurrence.

After drying out the asphalt surface resumes its normal appearance, rolling out smoothly under traffic, but the thickness of the pavement is decreased. The same thing will happen again under like conditions until a depression or hole is worn and repairs are necessary.

Enough is known, as has been said, to show that the weaker poorly graded mixtures lacking in bitumen and made with unsatisfactory asphalt cement suffer most from scaling. It is also much more in evidence where the base is weak. Mixtures having a filler of Portland cement are the most resistant, and finally it never occurs in a pavement thoroughly well constructed, such as that on Fifth Avenue in New York, or those properly laid in London and Paris; that is to say, it can be avoided entirely if the proper precautions are used. The watering-cart and lack of cleanliness are great aids to the production of scaling and, in fact, to the general diminution of the life of an asphalt pavement, but this is a condition the consideration of which must properly be taken up under the head of the effect of environment upon such surfaces.

Displacement of Asphalt Surfaces. — The displacement of asphalt pavements under traffic resulting in a rolling or wavy surface was a serious defect in the early days of the industry. It was due to the fact that the asphalt mixtures were unbalanced, the mineral aggregate was not properly graded, and the bitumen was present either in too small or too great an amount, with the result that the surface, not having sufficient internal stability, moved upon the more or less smooth hydraulic base, to which it was not tied by any intermediate course, under the pressure and impact of traffic. It has even moved in cases where such a course exists where the stability is unusually small. Defects of this description, which were at one time common, have been avoided not only by the introduction of a binder or paint course, but also, in the few surfaces constructed in recent years without such a course, by the greater stability of the surface mixture.

Displacement of the surface and formation of waves in asphalt surfaces do, however, occur occasionally at present, and this has been found to be due to the percolation of water through an open binder course, and its attacking the under surface of the wearing surface of the pavement, thus reducing its stability and permitting of the movement of the upper portion of the surface upon the loosened lower part. This occurrence is particularly noticeable where a pavement of this form of construction adjoins a street railway track which is not stable, vibrating and admitting water between the rail and the pavement. Such occurrences bring out very strongly the injury to all forms of pavement, of an unsatisfactory track construction, and of the difficulty of maintaining any pavement under such conditions.

Expansion of Cement in the Foundation.—The surface of an asphalt pavement has been at times raised transversely into waves by the expansion of the cement used in the construction of the base with the direct result of raising the latter at points of least resistance generally at joints between different days' work and the immediate elevation of the asphalt surface above these points. This has occurred with both natural and Portland cement, but usually with magnesian cements of the former type. When the expansion has ceased after the lapse of several years, removal of the excess of base and replacement of the surface at a normal grade obviates any further trouble.

Deterioration of Asphalt Pavements Due to Environment.—Deterioration in asphalt surfaces is brought about, even in those of the best form of construction, or to a much greater degree, of course, in those which are poorly constructed, by the nature of the environment to which they are subjected.

Difficult climatic environment is something that cannot be escaped and must be met as well as possible by the form of construction of the pavement and by the character of the surface mixture with which the pavement is constructed. That this must be accommodated to the climatic conditions which it is to meet is apparent and is generally understood, at least as far as temperature in its relations to latitude is concerned and with reference to sudden falls in temperature. The unfavorable environment due to prolonged humidity is, however, the most serious condition to be met, especially where the traffic is heavy, the surface not kept clean, and the air temperature for long periods lying between freezing and 45° F. As examples of the former condition might be cited the climate of St. Paul, Omaha, and New Orleans.

In the latter place it is very necessary to make the surface with a bitumen sufficiently hard in consistency not to prove undesirable in the summer months, as the temperatures in winter are not low enough to produce cracking. For this purpose a cement of 50 penetration on the Bowen machine is usually employed. In St. Paul, on the other hand, where the winter temperatures are very low a penetration of 90 is used. A cement of this degree of softness will naturally result in a pavement which marks up to a notable extent in the summer when first laid, but this disagreeable feature disappears after the second winter, and such a surface does not crack as would those laid with a harder cement.

A still more difficult climatic feature to meet is that of sudden drops in temperature, often as much as 50° in a few hours, which are met with in cities like Omaha. The immediate contraction caused by such a drop is so great as to overcome the elasticity or ductility of the bitumen, and cracking can only be prevented by using in the mixture as it is originally laid a very soft asphalt cement. An example of such a surface, that laid on Thirty-ninth Street in Omaha, Neb., will serve. It was so soft when it was completed and marked so freely that it was not at once accepted by the city. To-day it is the only pavement of its age in that city which has not cracked and now does not mark exceptionally under the hottest summer suns.

Experience has taught how these difficulties may be met with in the manner described, but pavements constructed by an inexperienced contractor, with an unbalanced mineral aggregate which will not permit the use of cement of sufficiently soft consistency, will inevitably show cracks in a colder climate in the course of two or three years.

A still more serious climatic condition to contend with is that met with in climates where there is excessive humidity in the winter months. Where such a condition exists only the most carefully prepared surface mixture will resist the combined action of moisture and heavy traffic. This was well illustrated in the earlier attempts to lay asphalt pavements in London, Glasgow, and on the northwestern Pacific Coast. It is even met with in some of our cities on the Atlantic Coast where asphalt pavements are placed on very heavy-traffic streets. Much of the earlier scaling in New York City was due to humidity combined with temperatures between 45° and the freezing-point. Below a freezing temperature scaling and disintegration due to this cause does not take place.

The deterioration of an asphalt pavement caused by the unfavorable environment produced by the leakage of coal-gas from gas-mains is an important one and has already been discussed under the heading " Disintegration."

Attention has already been called to the fact that asphaltic paving mixtures will not withstand the constant action of ground or running water, and where they are subjected to such an environment they will inevitably deteriorate more rapidly than is necessary. The remedy for defects due to the constant action of water is the removal of the cause by the introduction of proper provisions for drainage.

Asphalt pavements also suffer in one or two of our cities from flushing with water under a very considerable head with a hose and nozzle. No surface of any description can be expected to withstand such hydraulic mining. If it is carried on the city must expect to have the cost of maintenance of its asphalt streets much increased at the end of the guarantee period, and this will be the greater the more inferior the asphalt surface mixture is in the beginning.

A still greater cause of deterioration of asphalt pavements is found in the lack of cleanliness and general neglect. If the pavements are not carefully cleaned and filth is allowed to lie upon the surface for a great length of time, becoming mud as soon as they are sprinkled or rained upon, the deterioration is very rapid and even worse than when they are subjected to the action of clean water. Permitting mud and slime to remain upon an asphalt surface displays great ignorance, upon the part of public officials of the nature and behavior of asphalt pavements and should never be allowed to take place. For the same reason asphalt pavements should never be sprinkled if possible. The dirt should be removed and the situation not temporized with it by converting it into a slimy mud. This is doubly the case since such a slimy coating results in making the pavement extremely slippery, a feature not inherent in the asphalt surface itself, but attributable only to the film of mud.

Finally, asphalt surfaces in cities like New York, suffer enormously from the constant disturbance to which they are subjected by being taken up in connection with underground work. Though an asphalt pavement can be repaired more readily than any other, its constant removal and renewal cannot but injure it, as the foundation in such cases is never as rigid as the original. It can be asserted without doubt that not only asphalt pavements, but all others in a large city, can never be kept in a state of perfect maintenance until pipe galleries are provided under the streets which shall do away with the constant opening of the surface. In some of the streets of New York, from one-third to more than the entire area of the street has been often renewed in the course of the guarantee period for this reason.

Deterioration Due to Natural Wear and Neglect of Maintenance.—An asphalt surface is naturally more or less deteriorated by usage, like all materials of construction, and the amount which it suffers in this respect depends entirely upon the character of the original workmanship and the traffic and other conditions to which it is to be exposed. Some asphalt pavements under light traffic, such as that opposite the Arlington Hotel in the city of Washington, have given good service for 30 years and may be expected to last much longer. On the heaviest traffic streets constructed with the greatest skill some minor repairs may be expected at the end of from 3 to 5 years, depending upon the rigidity of the base which supports the surface and upon the manner in which these repairs are made, the extent of its deterioration will largely depend. The question of maintenance will be discussed in the following chapter.

SUMMARY.

To the general reader the preceding chapter will probably be one of the most interesting and instructive in the book, and it should be read in detail, as it explains the reasons for defects in and the causes of the deterioration in asphalt surfaces. The chapter may be summarized briefly as follows:

Defects in asphalt pavements are, to the greatest extent, to be attributed to faults of construction.

1. Due to improper specifications for the form of construction, the fault of the city officials.

2. Due to careless construction on the part of the contractor, and also

3. To improper maintenance when the age of the pavement is such that it should be given careful attention, as unfortunately the American public and many city officials seem to believe that when a street is once paved it should be expected to last forever without maintenance.

4. The action of illuminating-gas escaping from the mains.

5. Constant opening for underground work.

CHAPTER XXVI

MAINTENANCE OF ASPHALT PAVEMENTS.

THE question of the proper maintenance of asphalt pavements demands, but has not received, very careful consideration on the part of most of our municipalities and municipal officials, but it fortunately is receiving more to-day than in the past. Owing to the fact that asphalt pavements have generally been laid under guarantees by the contractor for their maintenance for a considerable period, a custom which, as has been said,[1] is rapidly disappearing, too little consideration has been given to their maintenance after its expiration. As a result of this, they have deteriorated very rapidly when thrown upon the hands of the municipality, and their condition has become such as to cause very unfavorable comment and great dissatisfaction. In a few cities, such as Washington, D. C., it has been demonstrated that there is no difficulty in maintaining an ordinary asphalt street in good condition for from 15 to 20 years, at a moderate cost, as has been shown by Capt. H. C. Newcomer in a report published in the *Engineering News* for February 18, 1904, where he shows that of the 2,425,732 square yards of bituminous pavements maintained by that city, of which not less than 2,161,181 square yards are laid with Trinidad Lake asphalt, the cost of maintenance was as follows, the average age of the surfaces being about 14.8 years, while there are over 700,000 square yards that are over 18 years of age. He also shows that the average age of the areas resurfaced during the fiscal year ending July 1, 1903, was 21 years, and this may be regarded as well within the limits of the duration of a standard asphalt pavement, if it is properly maintained during the period, especially as the older mixtures laid in Washington were by no means up to the standard of excellence of those which are now being put down.

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[1] See page 445.

COST OF MAINTAINING ASPHALT PAVEMENTS OF VARIOUS AGES AT WASHINGTON, D. C.

Age in Years.	Area, Square Yards.	Cost of Repairs for the Year.	Average Cost per Square Yard per Year.
5	1,841,435	$11,897	$0.0065
6	1,809,869	13,965	.0077
7	1,747,461	31,385	.0180
8	1,653,811	38,531	.0233
9	1,597,313	42,871	.0269
10	1,476,575	38,500	.0260
11	1,292,200	43,003	.0333
12	1,068,848	42,270	.0396
13	913,795	31,546	.0345
14	804,420	28,435	.0354
15	698,826	21,576	.0309
16	608,117	23,479	.0386
17	560,823	18,913	.0338
18	504,995	23,012	.0456
19	374,800	11,951	.0319
20	272,040	7,182	.0264
21	192,643	3,879	.0201
22	104,001	2,887	.0280
23	36,332	678	.0187
24	35,647	1,268	.0356

Neglect of maintenance, however, has resulted in quite a different condition in many other cities. There are one or two cities in the United States where, at the expiration of the guarantee period, no attempt is made at further maintenance, and, as a result, the asphalt pavements in these cities in a few years are in a wretched condition, arousing comment and adverse criticism of this form of pavement on the part of all the citizens. This can in nowise be attributed to the character of the pavement itself, but to the narrow policy pursued by the public officials in charge of the streets. Nothing can be so far from economical as to allow an asphalt pavement to go without repairs when they are needed, as, in this case as in all others, a "stitch in time saves nine."

On the other hand, there are numerous cities, such as Philadelphia and Washington, which have met with no difficulty whatever in maintaining their asphalt pavements in good condition under the contract system, a proper amount of funds being made available in the spring of the year. In at least one other city where the money is not available until mid-summer, July 1st, the contract system has not proved as desirable. In several cities, the failure of the contract system has been due more to the promiscuous way in which cutting up of the pavement is permitted by the city authorities, than to the manner in which repairs are made.

This situation has been discussed, as far as maintenance is concerned, in an article by Mr. S. Whinery, in *Engineering News* for May 9, 1907. He says in part:

"It cannot be denied that the condition of asphalt pavements in most cities is unsatisfactory, while in many it is deplorable and is rapidly becoming intolerable. To attribute this condition to inherent inferiority of this kind of pavement, as many people do, is wholly unwarranted. Everything considered, a well constructed and properly maintained asphalt pavement is not inferior to any other kind of pavement now in use. At the same time it must be conceded that an asphalt pavement usually requires attention and repairs at an earlier period in its life than most of the other pavements in common use, and it is probable, though not yet certain, that the total cost of maintenance during its useful life is also somewhat greater. It is certain that it requires more frequent and careful attention during its life to keep it in a proper state of repair than do stone or brick pavements. It is often the case that high grade articles or structures require more careful and skillful attention than the cruder varieties of the same class. It will certainly not be claimed that the value of a pavement may be measured by the amount of neglect and abuse it will endure."

"As the first important step in this direction the city must avoid, in the contract and specifications, requirements that are indefinite and ambiguous, and under which the contractor's duties cannot be clearly determined and enforced. We have seen that the long guaranty involves inherent conditions which, under the above stipulation, it is necessary to avoid. It should therefore be omitted from all future contracts. The art of constructing asphalt pavements is now so well understood that it is entirely possible to frame and administer specifications that will insure the production of a first class pavement, and the conditions that originally dictated these guarantees therefore no longer exist. The attempt thus to make the contractor responsible for the character of the work he does has not, in practice, been found effectual; moreover, our present knowledge of how the work should be done and the practicability of thorough inspection and supervision, renders the resort to such an expedient largely unnecessary. But if a time guaranty is still thought advisable, the period may be made so comparatively short that questions of faulty construction shall not be confused with those of maintenance. Barring accidental and unusual injuries, maintenance questions ought not to arise within a period of two years after the completion of the construction work, while palpable construction faults should be revealed within that time. The guaranty period should not therefore, exceed two, or at the most, three years. Maintenance after that period should be provided by the city."

Surface Heaters.—The question of the best way to maintain an asphalt pavement lies between cutting out the entire surface and binder, and the use of what are known as ‘‘surface heaters," which consist of a machine which directs a blast of flame from a series of naphtha burners upon the asphalt surface and softens it so that it can be removed to such depth as may be necessary to reach undisintegrated material, and then applying sufficient fresh material upon the area thus laid bare to renew the pavement to proper thickness. Such work has been extremely satisfactory in the past. As an example, the surface of Madison Avenue, between 23d and 26th Streets, in New York City, was entirely replaced in this manner in 1895, and has remained in excellent condition up to the present time. Of course the work cannot be done in wet or cold weather. At such periods the entire surface where disintegration occurs must be cut out to the foundation. The surface heater work is of course much more economical.

Under any circumstances, all maintenance and repair work will require the greatest skill in their execution, and too much care cannot be devoted to the details of it.

PART IX.

CONTROL OF WORK.

CHAPTER XVII.

INSTRUCTIONS FOR COLLECTING AND FORWARDING TO THE LABORATORY SAMPLES OF MATERIALS IN USE IN CONSTRUCTING ASPHALT PAVEMENTS.

In order that a laboratory examination, which has already been shown to be necessary, may be satisfactorily carried out the samples which are collected for this purpose should be carefully taken and according to some system.

The following directions have been prepared by the author for the use of superintendents and yard foremen.

The materials for the construction of asphalt pavements which require inspection in the laboratory may be classified as follows:

In Use in Foundation.

Broken stone, gravel, sand, hydraulic cement.

In Use in Binder.

Broken stone, bituminous cement.

In Use in Surface.

Stone for asphaltic concrete, sand, dust, or filler, refined asphalt, fluxing agents, either eastern residuum, California asphaltic oil, or other similar substances, and prepared from these materials, asphalt cement and the surface mixture itself.

These materials should be of satisfactory quality, and in order to determine this, samples should be sent for examination and report to the New York Testing Laboratory, Maurer, N. J. Following are directions, which must be closely observed, for collecting and forwarding these samples from every city where contracts are made and under way.

Samples and Specimens.—§ 1. To begin with, it must be explained that there is a decided difference between a sample and a specimen of any material. A specimen is some of the material selected to show its prominent characteristics, either of an inferior or desirable nature. A sample, if properly taken, represents the average composition and character of the material it represents.

Specimens are preferable to samples in certain instances and the reverse. When it is desired to emphasize the peculiarities of some material, a specimen is needed; but when a quantitative determination of its characteristics is to be made, a sample is necessary.

This distinction must be borne in mind in sending materials to the laboratory for examination, and good judgment must be used in regard to the most satisfactory means of arriving at the desired end.

Materials for Foundation.—§ 2. No samples of broken stone, sand, or cement need be forwarded, unless there is some question as to their suitability or quality, or unless they fail to meet the approval of the local engineers. Under the latter circumstance, two or three fragments of broken stone, a small sample box of sand, or four pounds of hydraulic cement should be sent to the laboratory, carefully identified as to the source from which the material comes and as to the parties furnishing the same.

Materials for Binder.—§ 3. No samples of broken stone or gravel for binder need be forwarded unless their quality be in question. Samples of asphalt cement for binder should be sent in the same way as those for surface mixture, if especially made for binder.

Materials for Surface Mixture.—§ 4. *Sand.*—In the case of sand supplies which have not been previously in use, and in every case at the beginning of a new season's work. samples of the one or more sands the use of which is proposed, or information in regard to the nature of which is desired, should be sent to the laboratory with definite statements as to source, whether river, lake, bank, etc., with the name of the party furnishing it and the locality in which the sand is found. These samples should weigh from two to three pounds, as much as will fill a cigar-box holding fifty cigars. The sample should be moistened and tightly packed so that the finer sand particles cannot sift out and be lost.

Samples of sand supplies which have been approved need not be sent again during the same season, unless the character of the deliveries appears to have changed decidedly or is suspected to have done so.

Samples of the sand in use on the platform, after it has been heated and screened should be sent to the laboratory once a week, when the plant is running. The quantity contained in the ordinary screw-top tin sample box is sufficient in this case unless otherwise directed.

§ 5. *Dust and Filler.*—The ground mineral matter, or dust, proposed for use as a filler should be sent in whenever a new source of supply is contemplated, and its use not begun until its quality has been approved.

From each delivery of such material a sample should be forwarded for examination.

The amount contained in an ordinary tin sample box is, in either case, sufficient for this purpose.

§ 6. *Refined Asphalt.*—Of refined Trinidad or Bermudez asphalt it is unnecessary to send samples from the paving plants, as this material has usually been inspected at the refineries. If, however, a shipment or any part of it appears to be of inferior quality or dirty, a convenient sized *specimen*, showing the defects noticed, should be provided for examination.

Asphalt from any other source which may happen to be in use, either experimentally or otherwise, should be sent in for examination in the form of a convenient sized representative specimen.

§ 7. *Fluxing Agents.*—A sample of each shipment or tank car of residuum, California soft asphalt or similar material in use for softening the harder asphalts in making asphalt cement, should be sent in a tin can *by express,* not less than a pint in amount.

Materials similar to blown oils can be sent in a box.

§ 8. *Asphalt Cements.* — Samples of asphalt cements from *every tank that is put in use* should be taken at that time and forwarded to the laboratory. If the consistency of that tank of cement becomes altered at any time during the day by the addition of oil or flux, a new sample should be taken.

If the asphalt cement in any tank is not exhausted in one day's run, and is in use again one or more days afterwards, samples for each of these days should be taken and sent to the laboratory, stating at the same time on a postal card, giving the number of the sample, the amount of oil or flux that has been added per every hundred pounds of cement estimated to be in the tank or dipping-tank at the time the oil was added. The screw-top tin sample boxes are to be used for this purpose.

§ 9. *Surface Mixture.*—Samples of surface mixture should be forwarded daily. For ordinary work one is sufficient, but where an important piece of work, subject to trying conditions, is completed in one day, two or three samples, taken at intervals while the mixture is being sent out, should be sent, to better illustrate the average composition of the surface.

Sampling Methods to be Employed.—§ 10. Unless the sampling of any material that is to be examined is carefully done, the sample will not be a representative one, and all work done upon it will be wasted. The results will be worse than useless—that is to say, deceiving. Too much emphasis cannot be placed, therefore, on the necessity for great care in this direction. In addition to what has already been said in regard to sending samples to the laboratory, the following suggestions for taking them should be followed closely.

§ 11. SAMPLING SAND:

1st. *From Pit or Bank.*—It must be borne in mind that in a pit or bank the sand lies in layers of different grading, which can almost never be taken out separately. Experience has shown that the best that can be done is to obtain a supply representing the average composition of the face of the bank. It is useless, therefore, to send specimens of sand from strata that cannot be isolated; or, if they are sent, specimens of the other layers in the bank should accompany them, with a statement of their relative thickness. A proper sample can be obtained by cutting a groove down the face of the bank and collecting the material in a pile and sampling as described below.

2d. *From Rivers or Lakeshores.*—In case it is desired to sample sands from river bottoms or lakeshores, it is impossible in ordinary cases to send in more than what is considered to be a representative specimen of the material, and final sampling must await deliveries on scow or car.

3d. *Deliveries of Sand* should be sampled as follows: Small scoopfuls or shovelfuls are taken from different parts of the pile, car, or boat load, and at different depths, in such number as will fairly represent the lot, three to six, from a canal-boat or barge and at depths of a foot or more, two from a car, and more or less from a pile, depending on its size. When the sand is in a pile the coarser grains will have rolled to the bottom, so care must be exercised not to take the sand from that point or the top alone. It is also well to dig some distance into the heap for some scoopfuls.

All the sand thus collected is dried, and, if large in amount, is made into a heap, cut back and forth with shovels like a batch of concrete and quartered, all but one quarter being rejected. This is continued until the heap is reduced to such a size that it can be passed through a Clarkson sampler, found at some of the works, or sampled by rolling first in one direction and then at right angles on brown paper and halving the mass, this being done several times until it is reduced to the required size for shipping.

4th. *Sand from Platform.*—Samples of the hot screened sand in use in the mixer should be taken from the spout of the sand-bin while the sand is running out freely into the box in the process of filling it. It should be collected by running a shovel or scoop back and forth several times along the edge of the distributor and then sampling the lot so gathered, either in a Clarkson sampler or by rolling on paper in the usual way.

Where there is no sand-bin a sample may be taken from the floor pile, as already described from a delivery pile.

§ 12. For sampling material of larger size, such as a barrel of refined Trinidad asphalt, it should be broken up on a tarpaulin and reduced to a size so fine that it can be treated in the same way as sand. Usually, as has been said, *specimens* only of rock, gravel, refined asphalt, and such materials are sufficient.

§ 13. *Sampling Asphalt Cement.*—It is difficult to always obtain uniform samples of asphalt cement. From the same bucket samples have been taken which varied as much as six points in penetration, owing to imperfections in the way it was dipped, a dirty bucket, or lack of uniformity in the cement. Great care should be used, therefore, to see that none of the conditions surrounding the dipping is abnormal. The dipping-bucket should be immersed in the cement until it is of the same temperature, and should then be moved about rapidly and submerged upside down and full of air to the middle depth of the still and then turned over, filled, withdrawn, and the tin sample boxes filled where dust cannot reach them.

§ 14. *Sampling Surface Mixture.*—A small wooden paddle with a blade 3 to 4 inches wide, 5 or 6 inches long, and ½ an inch thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

In the meantime a piece of brown manilla paper with a fairly smooth surface, 10 or 12 inches wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some *very firm* and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block, until the pat is about a ½ inch thick. The paper should then be opened and the pat trimmed with an ordinary table knife or spatula to a size of about 2½ by 4 inches, and a crease made along the narrower edge at a distance of ½ an inch to facilitate breaking off a piece for analysis when the pat is cold. Before the mixture is entirely cold the proportions of sand, dust, and asphalt cement, together with the sample number, date, and abbreviation of the name of the city where the sample is taken, is impressed upon it *with steel stamps* in letters and figures ¼ of an inch high. The paper is also marked with a rubber stamp, identifying it with the pat.

Additional information as to street, kind of dust, asphalt, etc., can also be provided for in blank spaces opposite headings printed by the rubber stamp. Such a stamp may be arranged as follows:

Name of city..............................
Sample number..............................
Date and hour..............................
Street..............................
Sand, coarse..............................
Sand, medium..............................
Sand, fine..............................
Filler, kind..............................
A. C..............................
Asphalt, source..............................
Flux, kind..............................
Penetration A. C..............................
Temperature..............................

The pat papers should be wrapped about the pat when cold and both placed in a heavy clasp envelope for mailing at fourth-class rates.

The pat paper is sent because the stain made upon it by the asphalt of the hot mixture, when considered in connection with the temperature of the mixture as it goes on the street, is of great value in determining whether a suitable amount of bitumen is present. Nothing should be written on the pat paper, as this renders the entire pat liable to letter rates in mailing, but the information required may be sent by filling in the blanks furnished by the rubber stamp on a postal card and mailing this at the same time.

§ 15. *Samples of Old Asphalt Surfaces.*—Where the determination of the characteristics of an old asphalt surface is desired a piece of the surface, together with the adhering binder course, if one has been used, is selected which will represent the average condition of the street. This should weigh at least 1 pound, and it is generally desirable that two or more samples from each street should be taken.

Collecting Samples.—§ 16. Samples of stone, cement, sand, refined asphalt, flux, etc., can be taken by any one about the plant who is competent to follow the directions which have been given but samples of mixture and asphalt cement should be taken by the plant foreman himself and by no other person. When there is a sub-laboratory at a paving plant the chemist in charge will have general supervision, and may, if requested by the plant foreman, attend to the collection of samples. The plant foreman will be held responsible in all cases, through the local superintendent, for the representative nature of the samples or specimens which are forwarded to the laboratory and for any deviation from the preceding instructions. It is especially urged upon the superintendents that they shall see that these instructions are carried out, and it is suggested that, to fully benefit by the results of the laboratory examinations, samples should be sent not only of the best but of the poorest work at each plant, in the latter case calling attention to that fact and giving the cause of the defect.

It is recommended that superintendents require their plant foremen to initial all reports from the laboratory in order that it may appear that the information given there has been brought to their attention.

Samples of asphalt cement and surface mixture should usually be taken as soon, after starting up the plant, as the work is going on regularly. The dipping-tank may be sampled at once so as to be able to mail it, as soon as cool, at an early hour. Any change in the character of the cement or addition to it demands a new sample, coupled with details of the change. If a second lot of cement goes into use later in the same day this should also be sampled immediately and sent to the laboratory as soon as possible.

A second sample of mixture should be taken if any decided change in it is made, such as increasing or decreasing the amount of asphalt cement, dust, or proportions of different sands.

The capacity of the laboratory for work is large, and if the rejection of any sample is necessary it is better done according to judgment exercised there than at the works.

Numbering and Mailing Samples.—§ 17. The samples of residuum, sand, and dust should be numbered consecutively, regardless of each other and of all other samples. For instance, the first sample of residuum sent for analysis would be No. 1, the second sample No. 2, and so on. The same would be true of the sand and dust, the first sample of each of these materials being No. 1 and the second No. 2, etc.

Samples of surface mixture will be numbered consecutively, but in case two samples of asphalt cement and only one of surface mixture are sent on the same day, the number of the second sample of asphalt cement should be the same as the first, but a figure " 2 " should be placed slightly above the right-hand upper corner and a " 3 " for a third corresponding to the same sample of surface. For instance, supposing that only one sample of surface mixture, No. 10, is sent on one day, but two of asphalt cement, the latter would be numbered 10 and 10^2. In this way the A. C. sample number will be made to agree with that of the surface mixture in which it was used. If two samples of surface mixture and two of asphalt cement are sent on the same day the numbers on each should correspond.

It must be insisted upon that too much care cannot be taken to so thoroughly identify samples that there may be no difficulty in recognizing their origin and source, even after the lapse of years. The habit of sending materials with a designation by number, or otherwise known only to the local superintendent, must be discontinued.

Samples from the plant should be mailed *at once*, or, if hot, as soon as cool, and usually at or about noon of the day on which the material represented by the samples is used. It may, of course, be necessary to mail others in the afternoon, but morning samples should in all cases be sent promptly and from the nearest letter-box to the works. The practice of sending samples to the superintendent's office should be discontinued. Duplicate samples can be sent to him for his inspection if he desires.

In order to check delays in the mails and in other ways it is well to mark the date and time of mailing on each package, and it should be made the special duty of some one person to attend to this matter, and he should be held responsible for mailing.

A new series of sample numbers for each material or class of materials should be started on January 1 of each year.

CHAPTER XXVIII.

METHODS EMPLOYED IN THE ASPHALT-PAVING INDUSTRY FOR THE CHEMICAL AND PHYSICAL EXAMINATION OF THE MATERIALS OF CONSTRUCTION.

The results of the examination of the materials in use in the construction of asphalt pavements will be of no value unless the samples or specimens representing these materials are collected with great care, so that they shall be truly representative of whatever is to be examined The directions given in the preceding chapter should, therefore, be followed in taking them.

The methods practised in the asphalt-paving industry in judging the different materials are as follows. It may be said in the beginning that these methods make no claim to great analytical accuracy, but afford that information needed in the industry with a maximum amount of accuracy and rapidity at a minimum expenditure of time. Many of them are only of relative value; that is to say, they do not furnish absolute data and can only be used when some well-known specimen of the same material is treated in a parallel manner and used as a standard of comparison, as will appear later.

Stone, Gravel, Slag, etc.—These materials, which form the coarser part of the aggregate in the foundation and the entire aggregate of the binder, can generally be examined by the hand-and-eye method without submitting them to laboratory tests. They should be free from adventitious matter, soil, vegetable débris, etc. They should be hard and when shaken together or passed through heating-drums should produce but a small amount of detritus. If necessary the percentage of this, formed in a given length of time when a definite weight of the material is revolved in a rattler, such as is used in testing paving bricks, may be determined.

For binder, stone should not be too porous and tests for the amount of water absorbed in twenty-four hours should be made.

As a rule the examination of these materials for use in the asphalt-paving industry is in no respects different from that which would be made were they to be used for other purposes. A more elaborate examination of any stone available for road construction will be made by the Office of Public Roads, U. S. Department of Agriculture, Washington, D. C., on application on forms supplied by the Department.

Where it is desirable to determine the proportions of stone of different sizes which go to make up the aggregate of crushed rock, as in arranging the grading of an asphaltic concrete, this can be determined by means of riddles. These consist of perforated metal set in circular wooden frames sixteen inches in diameter, with circular openings of the following diameter:

1 inch, $\frac{3}{4}$ inch, $\frac{1}{2}$ inch, $\frac{3}{8}$ inch and $\frac{1}{4}$ inch.

Binder Cement.—This is generally examined for its consistency alone by the same method as asphalt cement for surface mixture.

Sand.—This is examined as to the material of which the grains are composed, their shape, the character of their surface, the amount of silt, clay, loam, coal, or vegetable débris it contains, the size of the grains, or the sand grading as it is called, and the voids in the sand when compacted. The grains of sand are more often quartz than other minerals. At times some limestone grains or shells are present and rarely a considerable portion of the grains are silicates of igneous and volcanic origin, feldspar, hornblende, shales, magnetite, etc., as at Siboney beach, in Cuba, and in Mexico. At Santiago sands derived from coral reefs occur. These different minerals are determined in the usual way by examination under the glass and with reagents. The shape of the sand grains is important and is noted with a glass. It may be classed as sharp, round, medium, irregular, and with greater detail as to special peculiarities. The surface of the grains should be examined and note made as to whether it is smooth and polished, rough like ground glass, or between these grades, and if it is covered with any cementing material such as the ferruginous matter adhering to the New Jersey sands. The capacity of the surface of the grains for adsorbing aqueous vapor may also be determined with the object of learning the thickness of the film of asphalt cement which it will probably retain. The silt or clay and vegetable débris are detected by shaking a volume of 30 cubic centimeters of sand with 100 cubic centimeters of water in a graduated cylinder until thoroughly wetted and allowing the coarse particles to subside. A rough estimate of the amount of silt, etc., may then be made by the eye. The separation of sands into grains of various sizes by the use of sieves is the most important means of determining their availability for paving purposes. Another estimate may be reached from the character and amount of material passing the finest sieve in use and determining the size of the grains.

Determination of the Grading of Sands.—This is done with a series of sieves consisting of carefully woven brass wire cloth stretched upon a tin frame. These cloths were originally so selected that the average diameter of the particles which each sieve passed bore some definite relation to those passed by the next finer sieve. The average diameter of these particles as passed by the sieves in 1908 and the names given in the trade to the cloths are:

200-mesh	.085	millimeter
100- "	.173	"
80- "	.231	"
50- "	.377	"
40- "	.469	"
30- "	.595	"
20- "	1.002	"
10- "	2.133	"

The 200-mesh cloth was selected as a basis of measurement, being the finest available wire cloth, and it was found that the average diameter of the largest particles it will pass is .085 mm.

It seemed unnecessary to use any cloth, such as the 150-mesh, between this and the 100-mesh sieve, as the largest particles passed by the latter were only twice the size of those passed by the former. For the same reason an 80-mesh sieve was selected for the third sieve, as its largest particles were more nearly three times the size of those passed by the 200-mesh sieve than any other. A 50-mesh sieve passing particles about four times as great in diameter was selected, rejecting the use of the 60. From this point the increase in size is greater at each step, as no intermediate sieves are available or necessary. The particles passing the 40-, 30-, 20-, and 10-mesh sieves are approximately six, eight, twelve, and twenty-four times the diameter of the finest particles.

Obtaining satisfactory sieves of this description is not readily accomplished. Most of those found in the trade are made of poorly woven cloth or the cloth is so stretched in putting it on the frames that the interstices between the wires are much altered in size and no two sieves of the same number will agree. It is only satisfactory, therefore, to use sieves which have been carefully tested and compared among themselves and with a standard set, or to determine the factor for correction as recommended by Hazen.[1]

Sieves can now be had in such perfection from Howard & Morse, 1197 DeKalb Avenue, Brooklyn, N. Y., that a sand sifted on one set of sieves in Mexico and on another in the New York Testing Laboratory by different operators agreed remarkably well.

	Mexico.	New York Testing Laboratory.
Passing 200-mesh..........	3%	1%
" 100- "	6	5
" 80- "	8	7
" 50- "	35	35
" 40- "	25	28
" 30- "	13	12
" 20- "	7	8
" 10- "	3	4
	100	100

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[1] Report of Mass. State Board of Health, 1892, 541.

The finest cloth, in the 200-mesh sieve, is so delicate that it must be used with care and continually watched to detect any deterioration. Tearing away from the frame is a frequent occurrence, but such a defect or a small hole in the cloth can be stopped readily with soft solder, making the sieve as good as new. New sieves often have spots of solder in them where defects due to imperfect weaving or strains in mounting the cloth have been stopped out.

The sieves are made in nests, the finest being of the largest diameter, about 8 inches, as the greatest area of sifting surface is needed with this cloth. The diameter decreases until that of the 10-mesh sieve is only 5 inches. For storage and shipment the sieves thus occupy a small space.

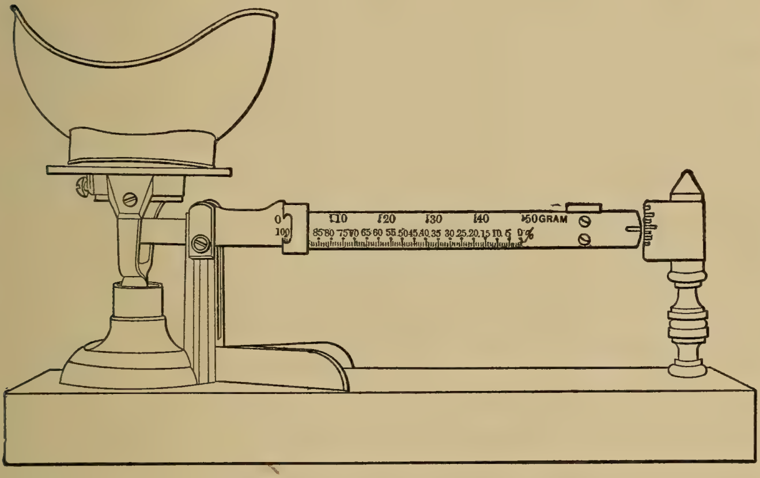

Fig. 30.—Sand Scale.

With such a set of sieves the size and grading of the particles of a sand can be satisfactorily determined and intelligently expressed. The operation of sifting and weighing is conducted as follows: A definite weight of sand, 50 grams, is taken. This is weighed out on a scoop and beam-scale especially constructed for use in making sand siftings and sensible to half a gram, Fig. 30. It is the ordinary No. 485 Fairbank's scale,[1] supplied to seedmen for determining the dust and dirt in flaxseed, modified to weigh a normal weight of 50 grams instead of 1 pound. The 50 grams are divided by graduations on the beam of this balance into 100 parts representing per cents, thus doing away with any calculations.

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[1] Fairbanks Co., New York.

The sand thus weighed out is thrown upon the 200-mesh sieve. It is important, however, before sifting is begun that the cloth of all the screens, and especially the three finest, be thoroughly cleaned with a stiff bristle brush from all particles which may have become fixed in the meshes. For this purpose a small stiff stencil brush, or one that is found in house-furnishing stores for scrubbing porous filters, may be used. After rubbing with a brush the screen is struck several sharp blows up and down to free it from loose particles.

The knack of using the sieves satisfactorily and quickly can hardly be described in print. After some shaking from side to side, the sieve is hit sharply on the table or hard surface to dislodge particles which have filled the meshes but will not pass through. Many attempts have been made to do the sifting by mechanical shaking devices and with sieves of all sizes at one time, but with little success. Where a large number of siftings is required, hand work is more reliable and quicker.

The most satisfactory mechanical device we have found is the "Per Se" Tier shaker,* which may be operated by power or hand, one of which is in use in the New York Testing Laboratory for screening concrete aggregates or when large quantities of sand must be considered.

The sifting is done over a clean piece of paper, and when nothing passes the 200-mesh sieve, all lumps of loam or clay which readily break up under the fingers having been rubbed to a powder on the sieve and the coarser grains cleaned from dust by attrition, the residue is returned to the scoop of the balance.

It will be noticed that some material at this point usually remains in the meshes of the wire cloth. This is allowed to remain there when the residue is poured from the sieve, and being more nearly the size of the grain passed by this sieve than the next larger is included with the 200-mesh or the coarser mesh sieves with their particular size grains and counted as passing that sieve. When the cloth of the sieve is brushed these grains are rejected, and, as all the determinations are made by loss and not by direct weighing, this is satisfactory.

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* Howard & Morse, Brooklyn, N. Y.

The per cent of material passing the 200-mesh sieve is arrived at as follows: The beam at the point where the poise is put to weigh out the original 50 grams of sand is graduated zero, and between this point and where the poise balances the empty scoop is graduated into 100 parts which may be read as per cents. The amount of material which has been passed by the sieve and rejected may then be seen at once in per cents on weighing the residue in the scoop, and so for subsequent sieves, subtracting of course each time the previous reading from the last.

It may be asked why the 200-mesh sieve is used first and why the results are not stated in per cents of materials retained on the different sieves, as is commonly the case. One of the reasons for using the finest sieve first is that if the dust or fine material is not removed at once much of it is blown away and lost in the process of sifting. As in this method the percentages are determined by loss, the amount disappearing during the sifting of the 200-mesh sieve first is of no consequence. Another is that the fine material adhering to the coarser grains is more readily separated from them by attrition in the finer sieves, and that the presence of the coarser sand aids in breaking up lumps and expedites sifting. In fact when sifting very fine material like dust or filler it is usual to place some coarse gravel not passing a 10-mesh sieve, or a few pennies, on the 200-mesh to aid in keeping the fine cloth clear and to break up lumps, thus doing the work of the coarser particles in sand or mineral aggregates which are entirely absent from the filler. The results are stated in per cents passing a given sieve rather than that retained, because this results in making a uniform statement and not some figures passed and some retained, and because it is easier to associate the percentages with definite sized particles rather than with sieves which will not pass them.

After the 200-mesh sieve, the others are used in order, and of course more rapidly as they become coarser. The greatest care is, of course, necessary with the finest sieve to clean the coarse grains and to break up lumps of clay, etc., for which the finger ends are most suited, as their pressure can be graduated and no undue force exerted upon the cloth or upon the particles which do not readily disintegrate.

The actual subtractions made in a sifting appear in the following facsimile page of a laboratory record, a rubber stamp being a decided convenience for reporting purposes:

No. 30402	Passing.
100.0	
4	200
13 4	
9	100
27 13	
14	80
57 27	
30	50
77 57	
20	40
88 77	
11	30
95 88	
7	20
100 95	
5	10

No. 30402	
Mesh No.	Per Cent. Passing.
Bit.	
200	4.0
100	9.0
80	14.0
50	30.0
40	20.0
30	11.0
20	7.0
10	5.0
R. 10	
Total. ..	100.0
Remarks:	

Voids in Sand and Mineral Aggregates.—An important consideration in connection with a sand or mixture of sands for use in asphalt pavements is the percentage of voids which it contains on compaction.

The ordinary methods of determining voids by measuring the volume of water that must be added to the compacted mineral aggregate to fill them, or pouring the compacted aggregate into a measured volume of water in a graduate and noting the increase of volume, are not satisfactory, because in the first way it is difficult to displace all the air in the voids or to know when it is displaced; in the second, because in light sand and sand mixed with filler a certain amount of the fine material is with difficulty persuaded not to float or leaves at best a meniscus which cannot be read.

The ordinary means of attaining ultimate compaction is also deficient in accuracy. At air temperatures the grains of any sand or dust are surrounded by a film of adsorbed aqueous vapor which prevents their packing as closely as possible. To attain satisfactory compaction the aggregate must be above the temperature of boiling water. It is necessary, therefore, to use hot sand in determining the voids in fine materials and the finer the material the more necessary it is.

The sand aggregate should be heated to about 250° F. in a small deep-form iron sand-bath[1] and then compacted in one of the following ways.

First Method.—A narrow-necked flask, graduated to 100 c.c., is filled with hot sand, the neck taken in one hand and with the other hand the body of the flask is struck back and forth from the neck to the bottom with a peculiar jarring motion with a wooden rod of about $\frac{3}{8}$ of an inch diameter and 12 inches long, covered for 3 inches with a piece of rubber tubing. The jarring settles the sand together rapidly in the flask and it is necessary to add more from time to time. When jarring ceases to compact the sand further it is, after having been brought to a definite volume, emptied on a balance and weighed. For ordinary purposes this weight divided by the weight of an equal volume of quartz, will give the actual volume the particles of sand occupy, and from the difference between this and the volume of the flask the voids are learned. When greater accuracy is required the flask with the hot sand must be allowed to cool to ordinary temperatures, to allow for contraction of the quartz in volume, and again filled to the mark. The specific gravity of the sand grains is ordinarily assumed to be 2.65, but it may vary, and the possibility of this can be determined at a glance. When this is the case the density must be determined, often in petroleum or alcohol when fine sand is present. The apparatus designed by D. D. Jackson, which has been described by him in a paper before the Society of Chemical Industry in 1904,* and which can be obtained from Emil Greiner Co., 45 Cliff Street, New York City, has been found to be very convenient for this purpose.

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[1] Eimer & Amend, No. 4555, 6-inch.

The advantage of this process is that the flask is filled with sand at once and there is no segregation of particles of different sizes, especially dust, which sometimes takes place in the next method.

Second Method.—The hot sand is taken as before, but it is put into a graduated 100 c.c. cylinder, 10 c.c. at a time, and compacted by tamping on a block of wood after each addition. When the compaction has reached its ultimate limit, this is known by a disappearance, especially with fine material, of a noise due to the presence of an air-cushion between the particles before this point is reached. Segregation takes place to a limited extent, especially in mixtures of sand and dust, but even with this error a greater compaction and density is obtained and less voids are found than with the flask method for the same aggregate, the difference being about 1 per cent in favor of the cylinder.

Volume Weight of Sand.—From the weight in grams of 100 c.c. of a sand or aggregate, obtained in the determination of the voids as just described, the weight per cubic foot in pounds can be found by multiplying by the factor .624. This is of value in determining what difference in the weight per cent of bitumen to expect from the addition of the same volume of asphalt cement to sands of different volume weight.

For example, an aggregate from a western city in 1899 weighed 124.5 pounds per cubic foot, from another 115.7. It is very easily seen that, with the same volume or weight of asphalt cement, added to each, the percentage by weight in an ordinary mixture will be much lower in the first than in the second city, and in practice it is found that in one case it was 10 per cent, in the other 11.3 per cent. This determination of volume weight therefore serves as an aid to our interpretation of our gravimetric analysis.

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*J. Soc. Chem. Ind. 24, 593.

Dust or Filler.—A dust or filler of ideal quality should consist of particles, all of which should be so fine that they will pass a 200-mesh screen. Everything coarser merely acts as sand. It is important, too, that the particles should be much finer than a size that will merely pass this sieve. They should be impalpably fine. 200-mesh sand is not the same as dust and is, in fact, often undesirable in a surface mixture.

In examining a dust or filler, therefore, it is necessary to determine with the 200-mesh sieve the percentage passing it and to study the character of that which passes. The latter examination can be made in two ways. As we have no sieve available for the purpose it must be done with a microscope or powerful lens which will show the character of the grains, or by elutriation.

Elutriation Method.—Until recently the only means of determining the fineness of a dust or filler has been by means of a 200-mesh sieve, but as the material passing this sieve might consist in whole or in part of grains as large as .10 mm. in diameter which can hardly be considered as dust, but are, on the contrary, only fine sand, something more satisfactory is demanded. This has been found in the elutriation process in use in soil analysis. Five grams of the dust to be examined are placed in a beaker about 120 mm. high, holding about 600 c.c. The beaker is nearly filled with distilled water, at a temperature of 68° F., and agitated with an air-blast until the dust and water are thoroughly mixed. On stopping the blast the liquid is allowed to stand exactly 15 seconds and the water above the sediment immediately decanted without pouring off any of the latter. This washing is repeated twice. The sediment is washed out into a dish, dried, and weighed. The loss in weight represents what may be considered as dust free from sand. The washing must be done with distilled water, since water containing salts in solution, as is well known, induces flocculation. This method can also be used with hydraulic cements, since the material acted upon by water is retained in suspension and removed, while that which subsides is practically unacted upon and can be dried and weighed without difficulty. The differentiation in this case can, however, not be carried beyond that resulting in 15 seconds. With other materials the differentiation of the particles not subsiding in 15 seconds can be carried further, if desired, by reagitating the decanted material and allowing the sedimentation to go on for 1 minute, 30 minutes, 1 hour, and so on. The preceding method is an adaptation of that proposed by Osborne for the separation of the particles of soil of various sizes, for further details of which reference must be made to the Connecticut Agricultural Station Annual Report, 1886, page 141, "Principles and Practice of Agricultural Analysis, Wiley, Vol. 1, page 196, and Hazen, 24th Annual Report Mass. State Board of Health, 1892, page 543.

Crude Hard Asphalts.—The analysis of crude asphalt is conducted in much the same way as that of the refined product except that it is necessary to determine, in the former, the loss of water and light oil, which are not or should not be found in the refined material. If there is any question as to the dryness of the refined material this should, of course, be first determined in the same manner as with the crude. The determination of water can be made in two ways.

Ordinary Method.—Ordinarily it is sufficiently accurate to weigh out 2 to 5 grams of the material in a crucible, or preferably on a watch glass to expose more surface, and to subject it to a temperature of 100° C., in a well regulated air-bath with the precautions described on pp. 534, 535, until it ceases to lose in weight to an extent of more than .2 to .3 per cent on successive heating. A greater concordance is not sought, as many asphalts continue to lose light oils gradually at this temperature. The oven which is used for this purpose in the author's laboratory is one of the Lothar-Meyer form, or a modification of this, which is fully described on page 536, Figs. 31 and 32. The degree of fineness to which the crude asphalt should be reduced before weighing out is dependent upon the amount of water it contains. In powdering some asphalt, such as crude Trinidad, the material, since it contains 29 per cent of water in emulsion with bitumen, begins to lose water at once. It can, therefore, only be broken into coarse lumps and not reduced to a powder until after a preliminary determination of the water thus lost by the coarse material. Other asphalts, containing only a small amount of hygroscopic or adventitious water, may be ground up at once, while some which are not readily powdered may be cut into small pieces. If it is necessary to determine the water absolutely it may be absorbed and weighed and the difference stated as gas or light hydrocarbons. This is hardly necessary from a technical point of view.

Alternate Method.—For asphalts such as crude Trinidad, in which the difficulties described above are met, a different method of procedure is advisable. The substance is very quickly reduced to a coarse powder only, in a mortar provided with a cover, through which the pestle passes. Five grams of it are spread out on a 4-inch watch-glass, and this is placed in vacuo over sulphuric acid for twelve hours and the loss determined. It should then be reground to a fine powder and exposed again in vacuo until it ceases to lose weight. The loss may be stated as water.

In the examination of a cargo of crude Trinidad for technical purposes, about 50 grams in small lumps are placed in a flat 8-oz. oblong tin box and dried to practically constant weight at 325° F. The results thus obtained are comparable with those obtained in the refining by steam at this temperature.

In whichever way the asphalt is dried a sufficient quantity is prepared and preserved in this condition in a tightly stoppered bottle, for analysis. Asphalts which cannot be reduced to powder are used in mass. The powdered asphalts have a slight tendency to absorb hygroscopic moisture and must be protected from the air.

In the dried condition crude asphalts can be considered, as far as analysis is concerned, simply as refined material, and all determinations should be done with and percentages calculated to this material, including the water or loss, by calculation, in the final results if desired.

Refined Asphalts.—Examination of refined asphalts in their most extended form include determinations given on the accompanying form, used as a convenience in reporting. With well-known asphalts but a limited number of determinations are necessary for the purpose of detecting the lack of uniformity or peculiarities in the material.

NEW YORK TESTING LABORATORY.

Test number.......... MAURER, N. J. ......
Source of supply..

PHYSICAL PROPERTIES.

Specific gravity, 78° F./78° F. original substance, dry.......
" " " pure bitumen...............
Color of powder or streak.................................
Lustre...
Structure...
Fracture..
Hardness, original substance...........................
Odor..
Softens...
Flows...
Penetration at 78° F..................................

CHEMICAL CHARACTERISTICS.

Original substance:
Loss, 212° F., 1 hour.................................
Dry substance:
Loss, 325° F., 7 hours................................
Character of residue..................................
Penetration of residue at 78° F.......................
Loss, 400° F., 7 hours (fresh sample).................
Character of residue..................................
Penetration of residue at 78° F.......................

Bitumen soluble in CS_2, air temperature..................
Inorganic or mineral matter...........................
Difference..

Malthenes:
Bitumen soluble in 88° naphtha, air temperature........
This is per cent of total bitumen......................
Per cent of soluble bitumen removed by H_2SO_4.........
Per cent of total bitumen as saturated hydrocarbons.....

Bitumen soluble in 62° naphtha.........................
This is per cent of total bitumen......................

Carbenes:
  Bitumen insoluble in carbon tetrachloride, air temperature.
  Bitumen more soluble in carbon tetrachloride, air temperature ....

Bitumen yields on ignition:
  Fixed carbon. ....

Sulphur. ....

Ultimate composition. ....

Remarks:

Physical Properties.—*Specific Gravity.*—The specific gravity of the dried asphalt is taken in a picnometer at 25° C. and referred to water at the same temperature. This temperature has been selected as the most convenient mean between the room temperatures of winter and summer, and is much more suitable in our surroundings than the lower temperature generally in use abroad, 15° C. Determinations at the latter temperature are much hampered by the great difference between it and our laboratory temperatures, the rapid expansion after cooling to 15° C. being difficult to provide for, as well as the condensation of moisture on the surface of the picnometer when the dew point is high, a room with the temperature in use for penetrations is always available for density and other temperature work. This temperature of 78° F. has therefore been taken as a normal one for all physical work on asphalts. The specific gravity of the pure bitumen extracted from those asphalts carrying a considerable amount of mineral matter, in a way to be subsequently described, is also determined in the same way.

The usual determination of the outward physical features of any mineral substance, *Color of Streak, Structure, Fracture, Hardness,* and *Odor* if any, are noted.

The color of the streak or of the powder of a hard asphalt is in certain cases characteristic. For example, in the case of refined Trinidad lake asphalt the powder is a bluish-black color, while that of the refined Trinidad land asphalt is much browner. Powdered gilsonite is of a very light-brown color. Powdered grahamite is quite black.

The structure of a solid native bitumen may be either homogeneous or it may show the presence of cavities containing gas, particles of adventitious mineral matter, shale or clay, or other peculiarities.

The fracture may be, in the case of very pure bitumens, conchoidal or semi-conchoidal, pencillated or hackley in the case of grahamite, or irregular.

The hardness of the original material, if it contains much mineral matter, may be stated in degrees of Mohrs scale, that of the pure bitumen in several ways. It is either brittle, like glance pitch, or soft enough to be penetrated with the needle of a penetration machine in which case the hardness is expressed in degrees of this machine.

The odor in the case of many bitumens is characteristic. That from Venezuelan asphalt, found near the Gulf of Maracaibo, is extremely strong and rank, while others are more purely asphaltic, especially on warming. The heat in any case brings out the odor to a degree not observed in the cold material.

Loss on Heating.—It is sometimes necessary to determine the loss which an asphalt suffers on heating for a time to definite temperatures. The length of time has been arbitrarily taken as seven hours and the temperature 325° F. and 400° F.

The determination is made as follows: In a No. 1 crystallizing-dish, $2\frac{1}{4}$ inches in diameter and $1\frac{5}{16}$ inches high, or 3 oz. deep seamless tin box of this size,[1] are placed 20 grams of the material under examination. The exact dimensions of the dish are of no great importance, as can be seen from the following determinations:

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[1] American Can Co., New York.

TWENTY GRAMS OF RESIDUUM AT 325° F. FOR SEVEN HOURS.

Dish number	1	2	3
Weight of dish	23.3465	18.1825	19.1855
Height of dish, outside	1.51″	1.47″	1.28″
Diameter of dish, inside	2.15″	2.15″	2.20″
Thickness of glass	.06	.045	.05
Volatile per cent	.925	.920	.950
Position in bath	Left	Right	Middle

Should it be necessary to use a very much larger dish the weight of the material to be taken should be calculated so that the volume which it holds shall bear the same relation to the surface exposed as in the case of the smaller dish. It is necessary to take separate portions of the substance for each determination, and not to attempt to determine the loss at 400° F. from the sample which has been previously heated at 325° F.

The dish is heated to the requisite temperature for the given length of time in an oven the temperature of which is uniform in all parts, something that is not as easily accomplished as might be supposed, and with the assurance that the materials are maintained at the proper temperature, a temperature which it has been found is not indicated by that recorded by a thermometer, that registers merely the temperature of the air in the bath. Such an oven is not only difficult to obtain, but the manner in which the best form is used is of great importance.

Form of Oven Employed in the Author's Laboratory.—Extended experience with various ovens thoroughly convinced the author that none of the forms ordinarily furnished by the supply dealers were satisfactory, especially if they are heated by the direct application of the flame to the bottom of the oven. The air-bath of Lothar-Meyer[1] was found to be by far the best, but inconvenient, owing to the fact that the interior is not readily reached. On this account an oven has been designed, possessing all the advantages of Meyer's form, but much more convenient for use in an asphalt laboratory. The accompanying illustrations show its construction, Figs. 31 and 32.

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[1] Berichte, 1889, 22, 1, 879.

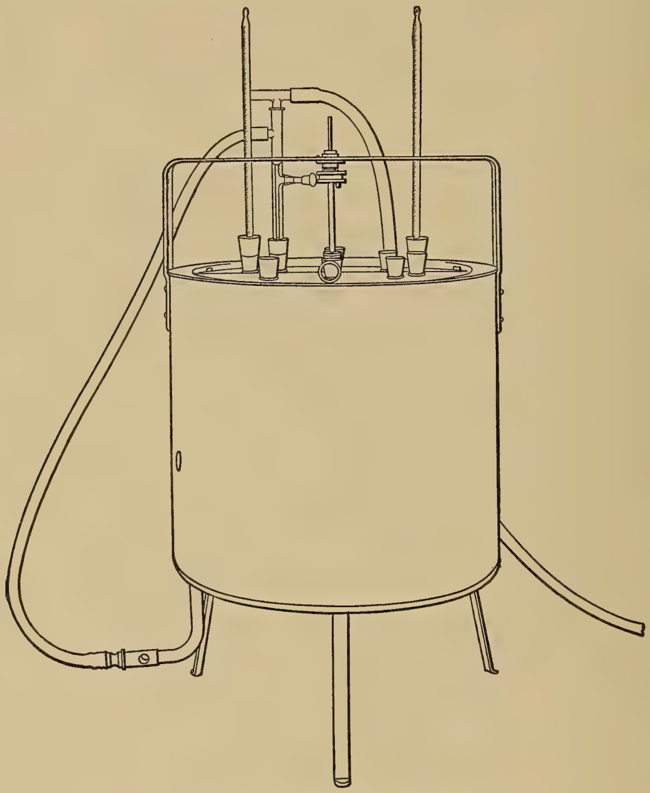

Fig. 31.—New York Testing Laboratory Oven.

It will be seen that the bath instead of being heated from the bottom is heated by a 10-inch ring burner immediately underneath the space between the oven itself and the outside wall, as in the Lothar-Meyer form. The perforations in this ring are necessarily systematically spaced to allow for the greater gas pressure at the point where the latter enters, in order that a uniform amount of

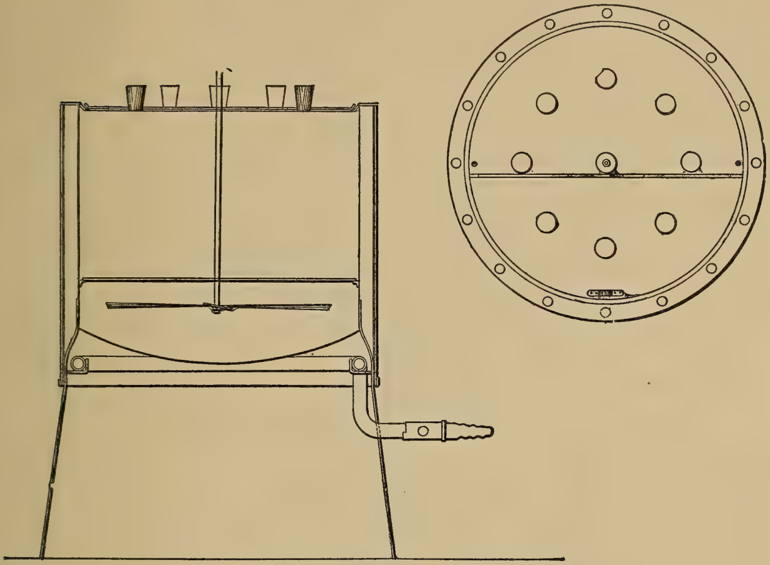

FIG. 32.—New York Testing Laboratory Oven.

heat may be furnished at all points in the circumference. If this is properly arranged, and the inner chamber of the bath is well made, no further precautions are necessary to avoid inequalities of temperature caused by the direct entrance of hot air from the burner into the oven. In standardizing the bath it is necessary that a number of thermometers should be inserted at different points in order to determine that the temperature at all points is uniform. If this is not the case the openings in the ring burner must be rearranged until this is accomplished. The interior of the bath, it will be noticed, is provided with a fan for causing a circulation of air to bring about still greater uniformity, this fan being moved by any convenient source of power.

The inner chamber is provided with a perforated shelf of metal. The dishes containing the material to be subjected to the desired temperature, it has been found, cannot be placed directly on this shelf with the assumption that they will not exceed the temperature recorded by the thermometers in the air circulating in the bath. The conductivity of the metal shelf is so much greater than that of the air that the dishes will attain a much higher temperature than the air in the bath. This difficulty can be avoided to a very considerable extent by placing a sheet of asbestos over the shelf; but even then the temperature of the material in the dish will be somewhat different from that of the air in the bath. In order to determine what the temperature of the former is it has been found necessary to use a thermometer, which is immersed in heavy residuum oil placed alongside the material under examination. The reading of this thermometer will give the temperature to which the material under examination is being subjected. The thermometer exposed only to the air of the bath is then observed merely for the purpose of detecting any sudden changes.

It will be noted that the cover to this bath is hinged so that it may be opened conveniently for inserting and removing the dishes containing the material under examination. It is provided with numerous openings for the insertion of thermometers and a gas regulator, and for the escape of the vapor of hydrocarbons which have been volatilized. The outer shell of the bath is covered with asbestos for insulating purposes.[1]

Melting or Flowing Point.—The solid native bitumens can have no definite melting point, for the reason that they are composed of mixtures of hydrocarbons. It is only possible, therefore, to determine rather arbitrarily the point at which the material softens or flows, and with special reference to the relation of this point toward some standard bitumen. This is determined as follows:

A crystallizing dish, about 2¼ inches in diameter and with 1½ inch sides, filled with clean mercury to a distance of ¼ inch from the top, is placed over a 20-mesh wire gauze and heated by a small flame protected from draughts by a chimney. On the surface of the mercury is placed a thin microscopic cover-glass, No. 2-0, carrying the specimen of asphalt under examination.

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[1] The bath is constructed for the author by the Hauck-Seebach Co., 291 Essex Street, Brooklyn, N. Y.

When dealing with hard asphalts that can be ground rather coarsely, several fragments which will pass a 40-mesh sieve and be retained on a 50-mesh sieve (about .50 mm. diameter) are spread on the cover glass and placed upon the surface of the mercury, covered with a funnel, from which the stem has been cut and the thermometer passed through the orifice until the bulb is immersed in the mercury. It is held in position by a clamp attached to the ring-stand holding the dish. Under the dish a burner is placed that can be regulated to a small flame and

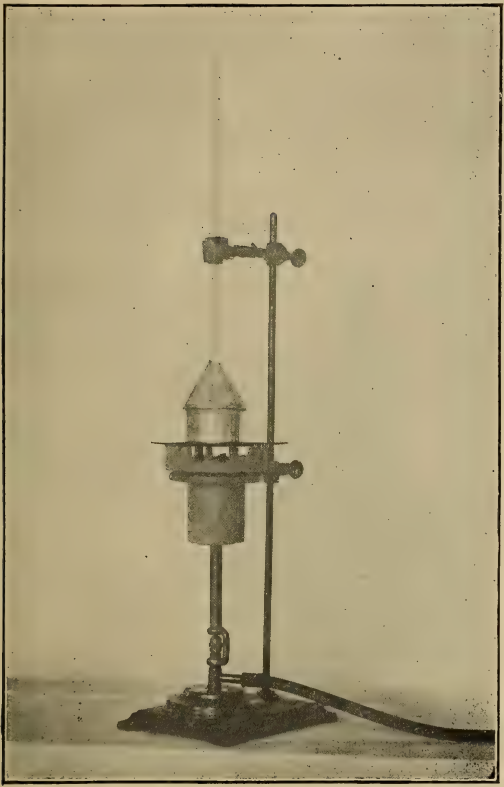

FIG. 33

heat, so that the rise of temperature will be from three to five degrees per minute. In a short time it will be noticed that the specimens will have changed from the brown or brownish-black color of the powder to that more nearly approaching the original, with a slight rounding of the individual grains. On further heating these globules flow together and form a thin sheet on the glass. The point at which the specimen begins to flow, as indicated by the thermometer, is noted as the melting or flowing point.

Asphalts that cannot be ground are softened and pulled out to a thread and cut into small pieces, about 1 cubic mm. Several pieces should be placed on the glass together, as one will serve as a check on the other, and thereby lessen the chance of error. The softening point may be noted by the rounding of the particles and the beginning of the flow, or when the specimen begins to spread out, which is always at the point of contact with the cover-glass, is set down as the flowing point or the temperature at which the specimen will melt.

Determination of Total Bitumen.—One gram of the dried or refined material, in a state of very fine powder, if possible, is weighed out and introduced into a 200 c.c. Erlenmeyer flask of Jena glass and covered with about 100 c.c. of bisulphide of carbon. It is then set aside for at least five hours, or overnight, at the temperature of the laboratory. In the meantime a Gooch crucible is prepared with an asbestos felt and weighed. This Gooch crucible is of special form with a large filtering surface. It holds 30 c.c., is 4.4 cm. wide at the top, tapering to 3.6 cm. at the bottom and 2.6 cm. deep. This is much better for percolation work than the usual narrow form of Gooch. The felt is made by beating up long-fibre Italian asbestos in a mortar, and suspending the finer particles in water and quickly pouring off from the coarse particles. Too much of the latter should not be removed, or the felt will be too dense. The decanted asbestos and water can be kept in a bottle for use. To prepare the felt the asbestos and water are shaken up and what is found to be a proper amount poured into the crucible, which has in the meantime been attached to a vacuum filtering-flask by the proper glass and rubber connections. As soon as the asbestos has somewhat settled the vacuum-pump is started and the felt firmly drawn on the bottom of the crucible. It is then dried, ignited, and weighed.

After standing a proper time the bisulphide is decanted very carefully upon the filter which is supported in the neck of a wide-mouth flask and allowed to run through without pressure. The flask after being tipped to pour the first portion is not again placed erect in order to avoid stirring up the insoluble material, but is held at an angle on any suitable base, such as a clay chimney. After all the bisulphide has been decanted more is added and the insoluble matter shaken up with it. This is allowed to settle and decanted as before, the insoluble matter being finally brought on the filter and washed with the solvent until clean. The excess of bisulphide is allowed to evaporate from the Gooch crucible at the temperature of the room. It is then dried for a short time at 100° C. and weighed. The loss of weight is the percentage of bitumen soluble in CS_2.

In the meantime, however, the bisulphide which has passed the filter is allowed to subside for twenty-four hours, if possible, and is then decanted carefully from the flask in which it has been received into a weighed platinum or unweighed porcelain dish. If there is any sediment in this flask it must be rinsed back into the Gooch crucible with bisulphide and the crucible again washed clean. The solvent in the dish is placed in a good draught and lighted. When all the bisulphide has burned, the bitumen remaining in the dish is burned off over a lamp and the mineral residue, which was too fine to subside, is weighed, if the burning was done in a platinum dish, or dusted out and added to the crucible if in a porcelain one. In the former case the weight is added to that of the Gooch crucible or subtracted from the per cent of bitumen, found without its consideration, as a correction. Care must be used in this method of procedure that the solvent does not creep over the sides of the crucible and that the outside is free from bitumen before weighing. In order to avoid this the crucible is supported in the neck of a flask with three constrictions, the neck extending above the top of the crucible and the latter being covered with a watch-glass. These flasks are made for the author by E. Machlett & Son, 143 East Twenty-third Street, New York.

Mineral Matter or Ash.—One gram of the same sample of material used for the determination of bitumen is weighed out in a No. 0 Royal Berlin porcelain crucible and burned in a muffle or over a flame until free from carbon. This must be determined by breaking up the cake of ash, moistening with water or alcohol, and observing if any black particles of coke are present. The weight of the residue is stated as inorganic or mineral matter.

The determination is of course not exact, sulphuric acid and the alkalies being volatilized in many cases, but it is satisfactory for technical purposes.

Naphtha Soluble Bitumen.—For the purpose of determining the percentage of bitumen soluble in naphtha distillates, 88° and 62° B. are used. It is extremely important that these naphthas should be of the exact degree specified, since differences in density will make an appreciable difference in the amount of bitumen extracted. The distillate should be that obtained from a paraffine petroleum. The density of each lot should be carefully determined with a Westphal balance at 60° F. and if it is too dense or too light, it can be brought to the proper density by diluting with a heavier or lighter naphtha as required. Redistillation of these naphthas is unnecessary as the products of distillation are no more uniform than the original naphtha.

It will be found very necessary that hard bitumens should be reduced to an impalpable powder before attempting to extract them, as otherwise the extraction will not be complete. The softer bitumens should be divided as much as possible.

The bitumen is usually extracted with naphthas of both densities in order to determine the difference in their action. If the amount extracted by each is the same or nearly the same it will point to the fact that the bitumen consists of hard asphaltenes mixed with light malthenes, the latter equally soluble in naphtha of both degrees of density, and but little intermediate hydrocarbons, or of the very hard asphalts fluxed artificially with some light oil. If, on the other hand, there is a very considerable increase in the percentage dissolved by the 62° over the 88° naphtha it may be assumed that the malthenes are well graded and natural constituents of the bitumen which is being examined. In certain cases, however, the use of the two naphthas is unnecessary. It would be useless to extract a maltha with a dense naphtha or glance pitch or albertite with a lighter one.

In determining the naphtha soluble bitumen in asphalts and other hydrocarbons it was the custom from 1887 to 1899 to make the extractions in small beakers, No. 0. One gram of the substance was weighed out and covered with a sufficient amount of naphtha, about 75 c.c., and placed on the steam bath and allowed to boil until the solvent became thoroughly saturated. It was then decanted through a weighed Gooch crucible and the residue successively treated until free from bitumen soluble in naphtha. As it was almost impossible to get concordant results in this way, on account of the loss of the lighter constituents of the naphtha and the consequent increase of density of the solvent, resort was had to the use of Erlenmeyer flasks, about 12 cm. high and 200 c.c. capacity. One gram of the substance was weighed out and boiled with the naphtha in a loosely stoppered flask for from one-half to one hour, according to the character of the material to be extracted. The solution was decanted as with the beaker method and the treatment repeated. The results were a slight improvement over the open beaker, but not entirely satisfactory. The use of a return cooler was then tried and gave good results with 62° naphtha, but as the loss of light hydrocarbons from the 88° naphtha could not be controlled, even in this way, any heating with this very volatile solvent was abandoned. The change in the two grades of naphtha on heating are shown from the following experiments:

EFFECT OF HEATING NAPHTHA AS IF USED AS A SOLVENT.

Degrees B.	Gravity 15° C./15° C.	Treatment.	Loss by Weight, Per Cent.	Loss by Volume, Per Cent.	Residue, Specific Gravity.
88°	0.6379	Return cooler	51.2	40.0	0.6523
"	0.6379	" "	65.6	37.0	0.6523
"	0.6379	Open flask	53.5	48.0	0.6585
62°	0.7321	Return cooler	3.0	1.0	0.7352
"	0.7321	Open flask	10.0	3.0	0.7393

It appears, therefore, that heating increases the density of both naphthas, and consequently their solvent powers, from inability to condense the more volatile parts, but that the change in the 62° naphtha is small, so that it can be safely heated to a slight extent.

As a result of these experiments all determinations are now made with cold naphtha by the following method:

One gram of the substance is weighed into a 200 c.c. Erlenmeyer flask, covered with naphtha and allowed to stand, as in estimating total bitumen, in fact the entire process is the same with the exception that one or two precautions must be observed. It is well not to attempt to break up any lumps with a stirring rod, as the substance, especially the softer asphalts, may then adhere to the rod or flask and be difficult to detach. It may also be necessary to treat the substance with several portions of the solvent instead of with two or three, as in the case of carbon disulphide. No heat is applied at any time in the process.

The naphtha soluble bitumens are frequently denominated petrolenes. The writer has recently suggested the name malthenes as bitumen of this nature closely resembles maltha in its consistency. Objection has been raised by partisans to the use of the name petrolene as leading to the conclusion that petrolene is a definite compound. Of course it is no more a definite compound than kerosene, but a mixture of various hydrocarbons like the latter. The objection to this designation must, therefore, fall to the ground, although petrolenes or malthenes may be more satisfactory as being less misleading.

Determination of the Character of the Malthenes or Naphtha Soluble Bitumens.—The determination of the relative proportion of saturated and unsaturated hydrocarbons which constitute the malthenes is very important in differentiating the solid bitumens. It is made as follows:

The 88° naphtha solution of the bitumen under examination is made up to a volume of 100 c.c. or reduced to that volume by evaporation. It is then placed in a 500-c.c. separatory funnel. An equal volume of the solvent naphtha is placed in another separatory funnel. The naphtha solution and the naphtha are then subjected to the action of 30 c.c. of sulphuric acid of specific gravity 1.84, the acid and the naphtha being shaken together for exactly three minutes. This is most important, since the action of the acid on the hydrocarbons in the bitumen under examination is not a fixed one, but will continue more or less indefinitely. After the shaking, the acid and the naphtha solution are allowed to stand overnight. The acid is then carefully drawn off and the shaking again repeated with another volume of acid of the same amount. This will require a shorter time for the separation of the acid and it can be drawn off within a few hours. If the second acid is very strongly discolored the acid treatment should be continued a third time. In the case of the blank determination with the plain solvent one treatment will be sufficient. The naphtha solution and the naphtha are then washed twice with water and afterwards once with a 5 per cent carbonate of soda solution, after which one further washing with water takes place. The naphtha solution of the bitumen which is being treated and the blank naphtha are then poured into crystallizing dishes 3¼ inches in diameter and 2 inches deep. In the plain naphtha is dissolved from .50 to .75 gram of some extremely stable petroleum residuum. The two dishes are then placed upon the steam-bath to evaporate the naphtha. In order to avoid creeping, the sides of the dishes are imbedded in a mass of cotton waste reaching to the top, as creeping is much diminished by having the sides of the dish warm. The evaporation is carried on on the steam-bath until the naphtha is volatilized and until the blank shows on weighing that the residue has returned to its original weight. It is then assumed that the other dish is free from naphtha, and from the water which the latter has dissolved in the process of washing. This, under the conditions observed in the author's laboratory, will require about six hours, but the exposure on the water-bath is generally continued one hour after the blank has reached a constant weight and further for fifteen minutes in an air-bath at 100° C. as control. The results obtained in this way are of no absolute value, but are of relative importance in comparing different fluxes and solid bitumens. It cannot, of course, be applied where the bitumen contains an appreciable amount of hydrocarbons volatile at 100° C.

Where 62° naphtha is the solvent its volatilization from the residue of bitumen which has been treated is extremely difficult, and such a determination is, therefore, not recommended.

Determination of Bitumen Soluble in Carbon Tetrachloride.—While in the large majority of cases the same, or nearly the same, amount of bitumen is dissolved by carbon tetrachloride as by bisulphide of carbon, bitumens are known in which hydrocarbons exist which are not as soluble in the former solvent—for example, one of the Venezuelan asphalts when overheated in refining, grahamite, and some of the residual pitches. The use of this solvent may, therefore, be desirable at times for the purpose of differentiating the native bitumens. The insoluble matter is extremely fine and is with difficulty retained on the closest filters. It appears to coagulate after several hours and in conducting the operation should be allowed to stand over night before filtering. A mild current of air passed for an hour through the solution accomplishes the same purpose, and may be used to hasten the analysis when desired.

One gram of the sample is treated with 100 cc. of the cold solvent, and with the exception of the precautions above noted, filtered in exactly the same way as with carbon disulphide.

The following data are given in illustration of the effect of different methods of handling.

Filtered as soon as dissolved	89.8%
" after standing 15 hours	83.6
" " " 48 "	83.6
" " blowing with air 1 hour as soon as dissolved	83.5

The commercial supply of carbon tetrachloride contains more or less carbon disulphide, and this naturally affects its solvent power, so that different lots may vary in this respect. As the carbon disulphide is much more volatile than the carbon tetrachloride, the majority of the latter can be removed by redistillation and rejecting all that which goes over below the boiling-point of the carbon tetrachloride, 76° C. It is also possible that it may be removed by blowing a current of air through the carbon tetrachloride.

Preparation of Pure Bitumen.—The preparation of the pure bitumen is a necessity where the percentage in the crude or refined material does not exceed 50 per cent, as under these circumstances its properties are so much concealed by the materials which are mixed with it that it is impossible to determine them, especially the hardness, softening point, and other physical data. The process which has been worked out for this purpose applies equally well to native bitumens and to artificial mixtures, such as old surfaces where it is desired to determine the consistency of the bitumen in the pavement.

Such an amount of crude, refined material or old surface is taken as analysis shows will afford about 20 grams of pure bitumen. At the same time 20 grams of a bitumen or asphalt cement of corresponding character and of known consistency is taken and treated in the same way as the material under examination. This is done for a control, as will appear. The original material and that for the control determination are placed, in small pieces, in a 600 c.c. Erlenmeyer flask and covered with 300 c.c. of redistilled bisulphide of carbon. This with shaking is allowed to stand overnight or until all lumps are broken down and the bitumen is dissolved. After thorough sedimentation the solvent is decanted as carefully as possible into a litre flask and 200 c.c. of fresh bisulphide poured upon the residue. This should be shaken and allowed to stand again until the insoluble matter has subsided, when the solution of bitumen is decanted as before and added to the first 300 c.c. This process is renewed with several portions of 100 c.c. of bisulphide until the residue is clean. The entire solution is allowed to stand overnight, again decanted from the finer sediment of mineral matter, and then swung in a centrifugal machine to remove as much of the still finer mineral matter as possible. If organic débris is present the solution must also be filtered, In case a more rapid method is desired for old surface mixtures, it is probably quite as satisfactory to swing the solution obtained in the first 300 c.c., as this is, of course, representative of the total bitumen, although only a portion of it.

If no centrifugal is available the different bisulphide solutions are well mixed, allowed to stand for some days and decanted. The solutions of bitumen, the one holding that under examination and the control, are, one after the other, placed in the same flask and the solvent distilled off as far as possible at the heat of a steam-bath. The hot and thick residue is poured into an iron dish, the 6-inch-deep-form sand-bath already described. This is placed on a suitable sized hole on the steam-bath and heated. The remaining bisulphide is largely driven off in this way. To prevent the vapor from the hot bisulphide from taking fire, it will do so without the presence of flame in contact with a hot steam-pipe, or from foaming over, a current of dry steam is blown over the surface of the liquid as long as vapor is evolved. Finally, the presence of the last traces of vapor are tested for with a small flame such as is used for determining the flashing-point of oils. If all vapor of bisulphide which can be distilled in this way has disappeared, the bitumen is in a condition to be brought over a flame or sand-bath and heated, with constant stirring, to a temperature depending on its softness, and until it is sufficiently fluid to be poured into a tin box for further treatment. This temperature should in no case exceed 325° F. These tin boxes are of the kind used in taking samples of asphalt cement for penetration and shipping them to the laboratory. A convenient form and size is the flat, 2-oz., screw top, Gill style.[1]

The bitumen or bitumens under examination and the control bitumen, after having been well identified in the tin boxes, are brought to the standard temperature and their consistency determined with the penetrometer. The control will usually be found to be softer by twenty or more points than in the original condition. If this is the case both or all of the extracted bitumens are put in an oven and heated for a length of time to 300° F., depending upon their excess of softness. It is important, of course, that the conditions in the air-bath are uniform, and that the same precautions should be used as in the determination of loss at 325° F. and 400° F., as previously described.

When the control bitumen has reached its original known consistency it is assumed that the bitumen or bitumens under examination have done the same thing, and the product is taken as the pure bitumen as it occurs in its original consistency in the crude or refined material or of the cement as it exists in the surface mixture.

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[1] American Can Co., New York.

Experience shows that this determination is reliable within five points on duplicate determinations.

Fixed Carbon.—The fixed carbon is determined usually on the pure bitumen according to the method recommended by the Committee on Coal Analysis of the American Chemical Society and published in the Journal of the Society for 1899, **21**, 1116. It is as follows:

Place 1 gram of pure bitumen in a "platinum crucible weighing 20 or 30 grams and having a tightly fitting cover. Heat over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle with the bottom 6 to 8 cm. above the top of the burner. The flame should be fully 20 cm. high when burning free, and the determination should be made in a place free from draughts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon."

FIXED CARBON IN BITUMENS.

	Extremes.		High Grade.
	High.	Low.	
Grahamite	53.3	35.3	53.3
Albertite	54.2	29.8	29.8
Gilsonite	26.2	3.3	14.5
Manjak, Barbadoes	....	....	25.0
Asphaltenes from Trinidad bitumen	....	....	25.8
Glance pitch	30.0	15.0	15.0[1]
Asphalts	17.9	10.8	14.2
Byerlyte (artificial asphalt)	....	....	14.3
Standard Asphalt Co.'s mine—soft gilsonite	....	....	7.3
Malthenes from Trinidad bitumen	....	....	6.3
Wurtzilite, Utah	8.8	5.3	8.2
Residuum, Pennsylvania field	....	....	3.4
Sunset oil, Kern Co., Cal	....	....	2.7

[1] Egyptian.

The residue minus the small impurity of ash in the pure bitumen is the fixed carbon, which should be calculated to 100 per cent with the volatile hydrocarbons, excluding the inorganic matter. As the committee states, this determination, like most industrial ones, is arbitrary, but it is of the greatest value in determining the nature of a bitumen quickly. Experience has shown that true hard asphalts have never been found which yielded more than 17.9 per cent or less than 10.0 per cent of fixed carbon, while grahamite yields over 53 per cent, albertite over 29 to 54 per cent, and some other bituminous materials characteristic amounts of fixed carbon.

Examination of Heavy Petroleum Oil.

Fluxing Agents and Oils.—The examination of materials under the above heading includes the determinations given in the accompanying forms:

NEW YORK TESTING LABORATORY.

Maurer, N. J.,............

Report on sample of Fluxing Agent received from....

Character of flux......................................
Date when sample was gathered.........................
Name of manufacturer..................................
Tank-car number.......................................
Sample number.................... Test number.......

Specific gravity, Beaumé........=Actual........At 78° F.
Flash-point......° F..................................
Loss, 212° F.,..hours.................................
Loss, 325° F., 7 hours................................
Loss, 400° F., 7 hours................................
Character of residue at 78° F.........................
Bitumen insoluble in 88° naphtha, air temperature.—Pitch..
Per cent of soluble bitumen removed by H_2SO_4............

Paraffine scale..

This material is................................quality

Remarks:

NEW YORK TESTING LABORATORY.

MAURER, N. J.,............

Test number:
Source of supply.....................................

PHYSICAL PROPERTIES.

Specific gravity, dried at 212° F., 78° F./78° F.............
Flows, cold test.......................................
Color...
Odor..
Under microscope.......................................
Flashes,° F., N. Y. State oil-tester.......................
Viscosity..

CHEMICAL CHARACTERISTICS.

Original substance:
  Loss, 212° F., 1 hour or until dry.......................
Dry substance:
  Loss, 325° F., 7 hours...................................
  Character of residue.....................................
  Penetration of residue at 78° F.........................
  Loss, 400° F., 7 hours (fresh sample)...................
  Character of residue.....................................
  Penetration of residue at 78° F.........................

Bitumen soluble in CS$_2$, air temperature...................
Difference...
Inorganic or mineral matter...............................

Bitumen insoluble in 88° naphtha, air temperature.—Pitch..
Per cent of soluble bitumen removed by H$_2$SO$_4$............
Per cent of bitumen as saturated hydrocarbons............

Per cent of solid paraffines................................

Bitumen yields on ignition:
  Fixed carbon...

Ultimate composition:

Remarks:

The methods used in making these determinations are, as a whole, the same as those described for hard asphalts with the following modifications.

Specific Gravity.—The specific gravity of oils or fluxes is taken on the material either dried at 212° F., or, if there are light oils present, volatile at this temperature, on some of the oil freed from water by being swung in the centrifugal.

Heavy fluxes too dense to employ a picnometer with are filled into an open specimen tube, 10 cm. long, 2 cm. in diameter, and holding about 27 grams of water, even with the top, which is ground flat and parallel to the base. The weight of this volume of oil at 78° F. is compared with that of water at the same temperature. Lighter oils are examined with the picnometer or Westphal balance. The industrial methods for the determination of the specific gravity of dense oils admit of much improvement and are now probably not accurate beyond the second place of decimals.

Mr. Lester Kirschbraun, chemist of the Chicago City Laboratory, Bureau of Engineering, describes the following method which is employed by him satisfactorily.

Take a test tube about a half inch in diameter and cut it off to give a 1¾ inch by ½ inch tube. Flare it out to carry a fine wire. Put about 10 grams of the oil or asphalt into it, and suspend it in an oven to remove air bubbles and drive off the water. Cool and weigh accurately in air and immerse in distilled water at 25° C. to a fixed mark on the wire and weigh. Previous to filling the tube with the sample, determine its weight carefully in air and in water at 25° C., immersed to the fixed mark. These weighings give the weights of the tube alone, in air and in water, and the combined weights of the tube and the sample, in air and water. The gravity is calculated in this way, representing,

Weight of tube in air........................	*a*
Weight of tube and sample in air..............	*b*
Weight of tube in water	*c*
Weight of tube and sample in water...........	*d*

$$\text{Sp. gr.} = \frac{\text{Wt. in air of sample}}{\text{Loss of wt. in water}}$$

in this case becomes

$$\frac{b-a}{(b-a)-(d-c)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When the gravity of the sample is less than unity, the second expression in the denominator is a negative $(d-c)$ quantity and is added to the original weight of the sample $(b-a)$, inasmuch as the buoyancy of the sample will overcome its own weight and to a certain extent will also reduce the weight of the tube in water, making c greater than d.

The formula in this case may be also expressed so:

$$\frac{b-a}{(b-a)+(c-d)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

When the gravity of the sample is greater than unity, d will be greater than c and the first formula applies without confusion. As an example, take a blown oil, the gravity of which was determined in our laboratory according to this method.

Weight of tube in air....................	a	=	4.7870
Weight of tube and sample in air.........	b	=	16.7900
Weight of tube in water, 25° C...........	c	=	2.8565
Weight of tube and sample in water......	d	=	2.6425

by formula (2)

$$\text{Sp. gr.} = \frac{16.7900-4.7870}{(16.7900-4.7870)+(2.8565-2.6425)} = \frac{12.0030}{12.2170} = .9817.$$

This may seem a bit complicated at first, but it will be noted that the factors a and c are constants which can be used for the same tube without change, and the calculation becomes very simple after a few trials.

The advantages of the method are in doing away with the inconveniences of handling a large amount of oil, and the ease with which air bubbles can be removed, particularly in handling refined asphalt. Of course it can be used only with oils which are viscous enough to be retained in the tube when under water.

Flow Test.—Some of the oil is chilled in a large test-tube and gradually allowed to attain the temperature of the room. The point at which it will flow in the inclined tube is the flow-point.

Color.—This is found by examining the reflection from the surface of the cold oil. It is intended to be that revealed by reflected and not by transmitted light through a thin film.

Odor.—The odor can be described as that corresponding to different kinds of known petroleum in the cold or on heating.

Microscopic Examination.—The appearance of an oil that has been heated is noted under the microscope to determine the presence of material insoluble in the main mass of the oil.

Flash-point.—The flash-point is determined in a New York State oil-tester.[1] The water-bath is of course removed and the oil heated directly with a flame of a size to raise the temperature at the rate of 20° per minute and a small flame from a capillary glass or metal tube is used for flashing. The flame should be applied at 5° intervals. The determination should be repeated on such oils as flash at unexpected temperatures. The water must be removed from the oil or flux before putting it in the tester cup, either by heat or by the centrifugal.

Open tests of high flashing oils are not reliable and at the best with the closed tester a reading of 5° intervals only need be sought.

Viscosity.—The Engler viscosimeter is used for this purpose, it being available for temperatures as high as 500° C.

The rate of flow in seconds of time is compared with that of an equal volume of water at the same or some standard temperature.

Loss at 212° F.—The water or loss of light oils at 212° F. is determined by weighing out 20 grams in a glass or tin dish, such as is described for use in the determination of loss at 325° F. in hard asphalts, and heating in the oven described, at the temperature named, until the oil has ceased foaming, or to practically constant weight. The precautions previously noted should be observed. When oils contain a large percentage of water this is better determined by the centrifugal method or by dilution with naphtha.

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[1] E. & A., No. 4160.

Drying an oil or flux for subsequent examination is done by heating a large volume in an iron dish over a flame, with constant stirring, unless it contains much light oil, when the centrifugal method alone can be used.

Loss at 325° F. and 400° F. in Seven Hours.—Separate portions of 20 grams of the dried material are taken for each determination and are heated to these temperatures in the manner described for solid bitumens. The residues from the oils and fluxes are examined after heating to these temperatures more in detail than those from hard asphalts which have been treated similarly.

After cooling and weighing the appearance of the residue is noted, especially as to whether it is smooth or granular owing to the presence of paraffine, the temperature at which it flows, whether it pulls out to a long string or is short. If it is so hard that it does not flow except on raising the temperature above 100° F., its consistency is determined with the penetrometer either at 100° F. or at 78° F. or at lower temperatures.

The residue should also be examined under the microscope to determine whether, owing to the nature of the fluxes, they have been at all decomposed at these temperatures with a separation of insoluble pitch, which is an evidence that the original flux must have been more or less cracked in the process of manufacture.

Total Bitumen; Inorganic Matter and Naphtha Soluble Bitumen.—These determinations are arrived at by the methods already described for hard asphalts.

As the oils and fluxes are more easily soluble it is unnecessary to let the solvents act on them for so long a time as in the case of hard asphalts. There is little object in using 62° naphtha with oils or fluxes, as there is too little difference between its solvent power and that of bisulphide of carbon with such materials to make it worth while. The residue insoluble in 88° naphtha, however, shows how much decomposition there has been in fluxes which have been subjected to excessive heat.

Determination of the Character of the Hydrocarbons in Fluxes.—The character of the hydrocarbons in any of the heavy oils used for fluxing purposes is determined by treatment with sulphuric acid after the method described for use with malthenes from hard asphalts.

Determination of the Amount of Hard Paraffine Scale.—The amount of hard paraffine scale contained in any flux or heavy oil can be readily determined by the author's modification[1] of the method of Holde.[2]

The method in detail is as follows:

The Determination of Paraffine in Petroleum Residues, Asphaltic Oils, and Asphalts Fluxed with Paraffine Oils.—For this purpose, one, two, or more grams, of the substance to be examined is taken and covered in an Erlenmeyer flask with 100 c.c. of 88° naphtha. The amount will depend on the paraffine present and on the percentage of oil which remains after the preliminary treatment with naphtha and acid. Of a residuum from eastern pipe-line oils one gram is sufficient, as the substance consists of a nearly pure bitumen containing from 4 to 12 per cent of paraffine. Ten grams of a residual pitch from asphaltic oil should be used, as this, in some cases, contains only 65.0 per cent of its bitumen soluble in naphtha, less than 50 per cent unacted on by acids, and only about 1.0 per cent paraffine. Several grams can be taken of a Trinidad asphalt cement, made of asphaltum and paraffine residuum, which contains 26.0 per cent of mineral matter and only 70.0 per cent of its bitumen is in a form soluble in 88° naphtha.

The object of the naphtha treatment is to separate the paraffine from substances of a non-bituminous nature and from some of the asphaltic hydrocarbons insoluble in naphtha which would be precipitated in the ether alcohol solvent and contaminate the paraffine.

By this means all the unsaturated hydrocarbons and those of an asphaltic nature, readily precipitated by alcohol from their ether solution, are removed and the possibility brought about of recovering the paraffine in a pure condition.

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[1] J. Soc. Chem. Ind., 1902, **21**, 690.

[2] Mitt. a. d. König, tech. Vers-anst, Berlin, 1896, **14**, 211. Abs. J. Soc. Chem. Ind., 1897, **16**, 362. Lunge, Chem. tech., Untersuchungs, Methoden. **3**, 9.

Some determinations made in the manner described resulted as follows:

PETROLEUM RESIDUUM FROM PIPE-LINE OIL.

Specific gravity, 0.93.

Number.	Weight taken.	Soluble in Naphtha.	Not acted on by H_2SO_4.	Paraffine.
	Grams.	Per Cent.	Per Cent.	Per Cent.
1	1.0	96.0	No treatment	7.95
2	1.0	96.0	89.5	5.55
3	1.0	Distilled *in vacuo*	No treatment	5.95

TRINIDAD ASPHALT CEMENT.

Number.	Weight Taken, Grams.	Soluble in Naphtha.	Not Acted on by H_2SO_4.	Paraffine.
1	10.0	....	No treatment	2.95
2	10.0	....	Treated	0.95

In each case the paraffine recovered after treatment was white and pure, while that obtained in the other way, even by distillation *in vacuo*, was colored. The results after treatment were, of course, lower and more correct.

The Trinidad asphalt cement was made from 100 parts of Trinidad asphalt and 20 parts of a residuum similar to the one analyzed. The asphalt contained, of course, no paraffine; the residuum, 5.55 per cent. The calculated amount in the cement is therefore 0.925 per cent, and 0.95 per cent was found.

In this way it can be determined whether the flux which has been used in the preparation of an asphalt cement has been derived from paraffine petroleum or from one having an asphaltic base, since if paraffine is found to such an extent as shown above it will necessarily point to the use of a paraffine flux, as no native solid bitumen in use in the paving industry contains paraffine.

Rapid Method for Paraffine in Crude Petroleum Fluxes and Residues.[1] **Standard Oil Company.**—The preceding method, while not lacking in accuracy, cannot be completed in a single day, and the following method, while yielding lower results, has the advantage of rapidity.

One hundred grams of the oil is distilled rapidly in a 6-oz. retort to dry coke.

Five grams of the well mixed distillate is treated in a 2-oz. flask with 25 cc. Squibb's ether; after mixing together thoroughly, 25 cc. Squibb's absolute alcohol is added, and the flask packed closely in a freezing mixture of finely crushed ice and salt for at least thirty minutes. Filter off the precipitate quickly by means of a suction pump, using a No. 575 C. S. & S. 9-cm. hardened filter, cooled by the above freezing mixture in a suitable apparatus.

Rinse and wash the precipitate with 1 to 1 Squibb's alcohol and ether mixture, cooled to 0° F. until free from oil. Fifty cc. of the washed solution is usually sufficient. When sucked dry, remove the paper, transfer the waxy precipitate to a small glass crystallizing dish. Dry on a steam bath and determine the weight of paraffine scale remaining in the dish.

Calculation.—Weight of paraffine scale divided by weight of distillate taken and multiplied by per cent of total distillate obtained from original sample, equals per cent of paraffine scale.

Fixed Carbon.—This determination is sometimes desirable with fluxes, especially with harder ones, to show the same facts revealed by the 88° naphtha extract. It is carried out in the same way as with hard bitumen.

Asphalt Cement.—Asphalt cement is examined to determine its consistency, the amount of bitumen, inorganic or mineral matter and organic matter, not soluble, it contains. Rarely the naphtha soluble bitumen is extracted and examined to determine the nature and quantity of the flux of which it has been made. The permanency of its consistency, when it is maintained in a melted condition at 325° F. for some time, may be noted.

The consistency of asphalt cement is determined in several ways, the most desirable of which in the laboratory is the penetration machine, for the reason that it admits of an absolute record in figures. Penetration machines have been designed by Bowen, Kenyon, Dow, and the New York Testing Laboratory. The two latter, however, have superseded the earlier and less desirable types.

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[1] Kindly furnished by Mr. George M. Saybolt.

The flow test originated by the Warren-Scharf Asphalt Paving Company, as well as the test by chewing, which is a rough one but always available, are of decided value and convenience for use at plants.

The construction of the various penetration machines and the method of using them is described as follows:

Bowen's Penetration Machine or Viscosimeter for Bituminous Solids.—*Principle of the Machine.*—The machine, Fig. 34, is designed to register on a dial in degrees, arbitrarily selected, the depth to which, a No. 2 cambric needle, attached to a weighted arm or lever, penetrates into the surface of the material to be tested when allowed to act upon it for one second at a standard temperature.

The machine has been described by H. C. Bowen, in the School of Mines Quarterly, **10**, 297.

The Dow Penetration Machine.—A penetration machine has been designed by Mr. A. W. Dow, formerly Inspector of Asphalt and Cements, of the District of Columbia, Washington, D.C., which in so far as it is based on the measurement of the millimeters to which a definite needle penetrates into the asphalt cement under a definite weight at a definite temperature is concerned, is a more truly scientific instrument than the one previously described. The readings by this machine are about 20 points lower than those obtained with the Bowen instrument, but it possesses the disadvantage that when large numbers of asphalt cements are to be examined at any one time it requires greater delicacy of manipulation and much more time than is the case when the Bowen machine is used. Fig. 35. Mr. Dow describes its use as follows:

"**Description and Directions for Using the Dow Penetration Machine.**—The object of the penetration test is to ascertain the softness of asphalt, etc., and is accomplished by determining the distance a weighted needle will penetrate into the specimens under examination.

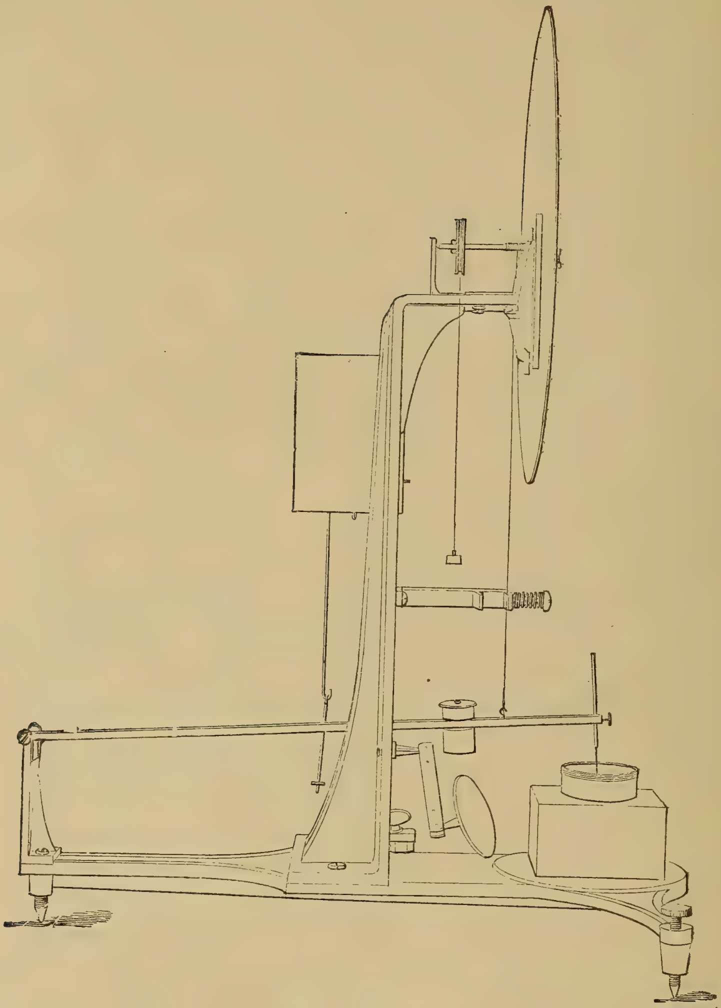

FIG. 34.—Bowen Penetration Machine.

"So that all tests may be comparable, a standard needle should be used, weighted with a constant weight. The tests should be made on samples at a standard temperature and be made for the same length of time in every case. The standards used in this machine for testing cements to see that they are of uniform consistency are a No. 2 needle, weighted with 100 grams, penetrating for five seconds into the sample at a temperature of of 77° F. (25° C.)

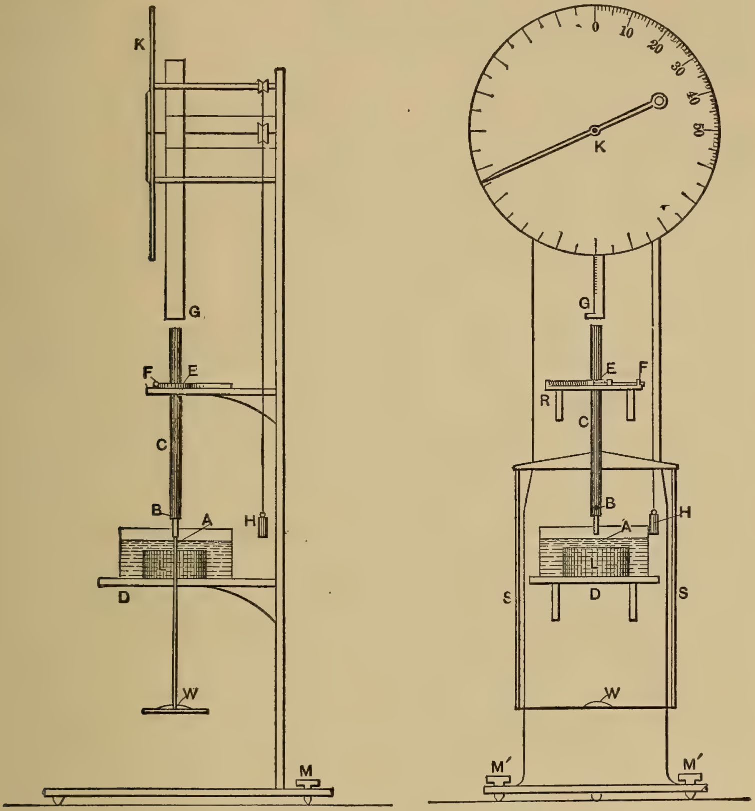

FIG. 35.—Dow Penetration Machine.

"The apparatus consists of a No. 2 needle A, inserted in a short brass rod which is held in the aluminum rod C by the binding screw B. The aluminum rod is secured in a framework so weighted and balanced that when it is supported on the point of the needle A the framework and rod will stand in an upright position, allowing the needle to penetrate perpendicularly without the aid of a support, thus doing away with any friction.

"The frame, aluminium rod, and needle weigh 100 grams with the weight on bottom of frame; without weight 50 grams. Thus when the point of the needle rests on the surface of the sample of material to be tested as to the penetration, it will penetrate into the sample under a weight of 100 grams or 50 grams as desired.

"The needle and weighted frame are shown in Fig. 35, side and front views of the entire apparatus put together and ready for making a penetration. D is the shelf for the sample, E, is the clamp to hold the aluminum rod C until it is desired to make a test, F is a button which when pressed opens clamp E. By turning this button while the clamp is being held open it will lock and keep the clamp from closing until unlocked. The device to measure the distance penetrated by the needle consists of a rack, the foot of which is G. The movement of this rack up or down turns a pinion to which is attached the hand which indicates on dial K the distance moved by the rack. One division of the dial corresponds to a movement of the rack of 1/100 cm. The rack can be raised or lowered by moving counterweight H up or down. L is a tin box containing sample to be tested which is covered with water in the glass cup, thus keeping its temperature constant. MM′ are leveling screws. A clock movement having a 10-inch pendulum is attached to the wall to one side of the machine. Make a mark P on the wall just at the extremity of the swing of the pendulum; a double swing of this pendulum, that is from the time it leaves P until it returns, is one second.

"The only other things necessary to complete the outfit are a large dish-pan, a pitcher to hold ice-water and a tin for hot water; a coffee-pot is a good thing.

"To make penetration tests place the materials contained in circular tins, along with the glass dish, under five or six inches of water in the dish-pan, which should have been previously brought to a temperature of 77° F. by the addition of hot water or cold water.

"While the samples are under the water it should be stirred every few minutes, with the thermometer and the temperature kept constant at 77° F. by the addition of hot or cold water as the case may require. The samples should remain under the water for at least fifteen minutes and in cases where they are very cold or hot, at least one-half hour. The most expeditious way to proceed in testing a sample just taken from a still or tank is to immerse it in ice-water as soon as it has hardened sufficiently and keep it there for ten minutes, then in the water at 77° F. and keep it there for fifteen minutes. When the sample has remained in the water for the specified time it is ready to penetrate.

"The aluminum rod C should be pressed up through the clamp E so that it will be at such a height that the glass cup will easily pass under it when placed on shelf D.

"A sample in tin box should now be placed in the glass cup and removed in it covered with as much water as convenient without spilling.

"The glass cup containing sample is placed on shelf D under C. Insert brass rod with needle into C and secure by tightening binding screw B, lower C until the point of the needle very nearly touches surface of sample; then, by grasping the frame with two hands at S and S′, cautiously pull down until needle is just in contact with surface of sample.

"This can best be seen by having a light so situated that, looking through the sides of the glass cup, the needle will be reflected in the surface of the sample. After thus setting the needle, raise counterweight H slowly until the foot of the rack G rests on the head of rod C; note reading of dial, place thumb of right hand on R and press button F with forefinger, thus opening the clamp.

"Hold open for five seconds and then allow it to close. The difference between the former reading of the dial and the present is the distance penetrated by the needle, or the penetration of the sample. Raise rack, loosen binding screw B raise rod through clamp, leaving the needle sticking in sample. Remove needle from sample, clean well by passing through a dry cloth, replace needle in C and the machine is ready for another test.

" Do not clean needle on oily cloth, or waste.

" Do not allow rack to descend too rapidly on rod C as it may force C through the clamp, thus spoiling the reading.

" After using the machine, leave it so the top of the rack is just level with its base. You will thus prevent dust from entering and getting into pinion. When not in use keep machine covered with a cloth to protect from dust.

" Examine point of needle from time to time with magnifying glass to see that it is not injured in any way.

"If the needle is found defective remove by heating the brass rod, when the needle can be withdrawn with pincers. Break eye from one of the extra needles and press into brass rod previously heated.

"If needle does not stay in well, insert it with a small lump of asphalt.

"If when this framework is supported on the point of the needle it does not balance so that the aluminum rod C stands perfectly perpendicular, the frame is bent and should be straightened until the rod stands perpendicular. This can easily be done by hand.

"If rack G does not descend readily of its own weight when counter weight H is raised, it is likely that dust has gotten into the pinion. To get at pinion to clean, remove dial K and bearing T, when pinion can be pulled out sufficiently far to clean.

"Never oil rack and pinion, as it prevents a free movement of rack.

"If machine is unsatisfactory write and explain trouble.

"**Test for Susceptibility to Changes in Temperature.**—The standards that I have adopted for this test are:

"The distance penetrated by the No. 2 needle into the sample at 32° F. in one minute with 200 grams on frame.

"The penetration at 77° F., as described before, and the penetration into the sample of the No. 2 needle in five seconds at 100° F. with 50-gram frame. In some cases I use 100 grams, which is preferable if the depth of the sample will permit. In all cases when you give a penetration of cement state in parentheses how it was made, as for example (No. 2N., 5 sec., 50 grams, 100°) means that the penetration was made with a No. 2 needle penetrating 5 seconds with 50-gram frame at 100° F.

"If a statement is made like this there can never be any doubt about the figures and they will be understood by all familiar with the machine."

New York Testing Laboratory Penetrometer.—In the Dow instrument, all the parts are of very light construction and require a certain delicacy of touch to use it satisfactorily, and consequent-

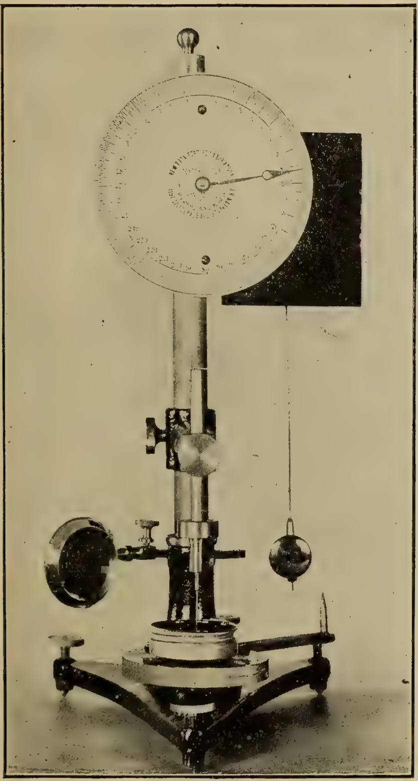

FIG. 36.

ly, it is not easily manipulated by such men as are found at paving plants, although these disadvantages are of slight consideration in the laboratory. The shelf upon which the sample to be tested is placed is fixed and the needle must, therefore, be brought

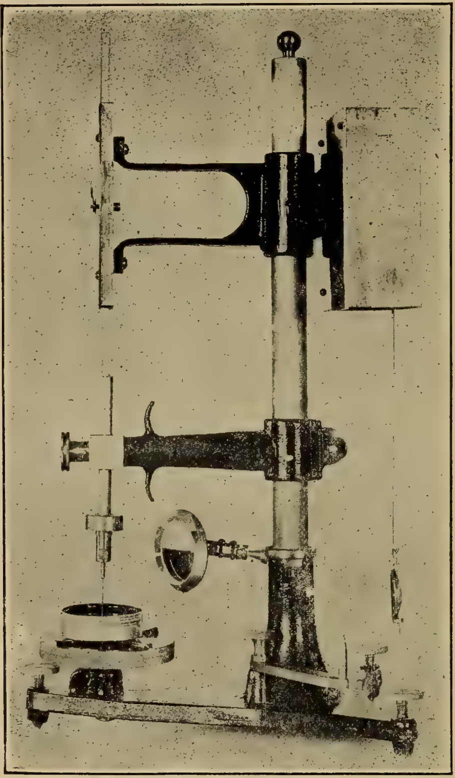

FIG. 37.

down toward the surface of the bituminous cement until it is in contact with it. On each side of the shelf which holds the sample are the two rods of the frame from which the weight which acts upon the needle is suspended. These are much in the way in adjusting the needle in contact with the surface of the bituminous cement, and restrict the size of the sample of the latter.

In the Penetrometer (Figs. 36 and 37), an attempt has been made to overcome these features, without seriously imparing the accuracy of the instrument. The sample to be tested, which may, if desired, be of large or small size, is placed upon a table which is supported upon a screw, enabling the needle to be set at zero, and the sample to be brought up to contact with the point by elevating it with the screw. The entire weight acting upon the needle is contained in the tube which holds it, and, being placed at the lowest possible point in the tube, does not tend to seriously divert it from the vertical on the release of the clamp and makes it possible to do away with the frame which is so much in the way in the Dow apparatus. The Penetrometer is given greater stability than the Dow apparatus by making a much larger and firmer clamp to hold the tube, while all the other parts of the instrument are rigidly constructed. The increased friction of the clamp on the rod reduces the extent of the penetration of the needle by one- or two-tenths of a millimeter, but this is practically of no consequence, as it is a variation not greater than that due to different needles or to the personal equation of various operators.

The determination of the depth to which the needle has penetrated is arrived at by a similar means to that employed in the Dow machine, a rack and pinion, but the rod to which the rack is attached is prevented from moving, not by a balance weight attached to a cord, as in the Dow machine, but by a spring exerting a slight pressure against its side. This does away with the opportunity for the cord and balance weight to be knocked out of place or lost, and makes the apparatus much more convenient to move from place to place. The penetration of the needle is registered in tenths of millimeters, on the same scale as in the Dow machine, and the time during which the weight acts is made five seconds instead of one, as is the case of the Bowen apparatus. The detail of the manipulation of the tests is the same with the Penetrometer as with the Dow apparatus, previously described.

The Penetrometer is manufactured by Messrs. Howard & Morse, 1197 DeKalb Avenue, Brooklyn, N. Y.

Flow Test.—The consistency of asphalt cements can also be controlled by means of a flow test. This is a comparative one and gives nothing but ocular evidence as to the relative softness of two cements at or near their flowing point. The test consists in making, in a suitable mould, cylinders $\frac{3}{4}$ inch long and $\frac{3}{8}$ inch in diameter, of a standard cement and of the one to be examined, placing them on a brass plate with corrugations corresponding in size to that of the cylinders and exposing them at an angle of 45° to a temperature at which the cements will soften and flow.

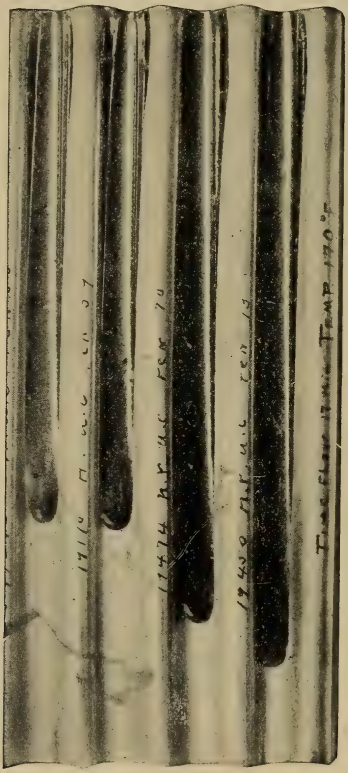

Fig. 38.—Flow Plate.

Cements made of the same asphalt and flux are of the same consistency if they flow to the same length, Fig. 38.

As a quick, rough test this is very satisfactory; but care must be taken that the cylinders are exposed to a uniform temperature and that one part of the brass plate is not hotter than another, which may readily happen if it touches hot metal or any good conductor. The plate, for safety, should only be warmed by air and should be isolated from contact with metals by asbestos, paper or wood.

Cylinders are made by softening the cement to be examined until it can be rolled out on a board to about the proper size. It is then pressed in a brass mould of the exact size, which is made in halves, and cut off to the right length with a hot knife. With any particular cement a weighed amount known to make a cylinder of proper size may be taken and rolled to the right length instead of using a mould.

The cylinders, while still warm, are pressed upon the brass plate until they adhere and allowed to come to a constant temperature by immersion in water before warming for the flow test. The cylinders must stick to the flow plate in the beginning or they may slide instead of flow. The flow plates are $8 \times 2\frac{3}{8}$ inches in size and have corrugations for four cylinders. As has been said the selection of some means of affording a uniform temperature is the most difficult one. In the New York Testing Laboratory, a carefully regulated rectangular air bath illuminated by a small incandescent bulb and containing a mica covered window in the door is employed. At the plants a box heated by a coil of pipe through which steam is conducted can be arranged; or, for rough work, the plate is placed over a stove without being in contact with the metal. In trying any new method of heating it is well to put duplicates of the same material on different parts of the plate and see if they flow alike. This will determine whether the oven is sufficiently uniformly heated for practical purposes.

Flows of Trinidad asphalt cements are made at about 160° F., others at somewhat lower or higher temperatures, as the case may demand. One kind of cement cannot, of course, be compared with that made from another bitumen, even if they have the same penetration at 78° F.

Composition of Asphalt Cement.—The percentages of bitumen, organic insoluble matter and inorganic or mineral matter in all asphalt cements can be determined exactly as in refined asphalts.

The naphtha soluble bitumen is sometimes sought with a view to its examination and the determination of the nature and amount of flux which has been used in making the cement. This is done in the same way as with refined asphalts or fluxes, but the naphtha solution is evaporated and the residual bitumen examined. Although it will contain the malthenes of the asphalt as well as those of the flux used in making the cement, the percentage of the former being known for any given asphalt, it is possible to calculate the latter if the cement has not been maintained at a high temperature in a melted state for too long a time with volatilization and loss of oil. From the physical characteristics and distillation the nature of the flux can generally be determined as between an eastern or California residuum, and the presence of coal-tar or dead-oil is easily detected.

The bitumen in asphalt cements holding much organic matter can be estimated only by percolation with the Gooch crucible, but in Trinidad and other cements carrying much mineral matter, when examined in large number, the bitumen can be more expeditiously determined by the centrifugal machine. The centrifugal machine in use for this purpose in the New York Testing Laboratory, at Maurer, N. J., is a large Troy laundry extractor with a basket 30 inches in diameter, which has been filled about the circumference with solid boxwood, leaving an opening 11 inches in diameter in the centre. In this boxwood are bored about three dozen one-inch holes to a depth of 6½ inches, sloping downward at an angle of 15°, provided with metal liners, in the bottom of which a piece of sponge is placed to form a cushion with water, and which in turn hold the glass tubes, about 1 inch in exterior diameter and 8 inches long, weighing 50 to 60 grams, in which, after being accurately weighed, is placed 1 gram of the asphalt cement stirred up with bisulphide of carbon to reach to a height not greater than 4¼ to 4½ inches in the tube and amounting to 30–35 c.c. of solvent. The tubes and substance thus prepared are placed in the centrifugal in such a way as to balance the basket and the power is applied to give a revolution of 1500 per minute. This is kept up for fifteen minutes, when the tubes are taken out and decanted carefully, without pouring off any sediment into flint 8-ounce wide-mouth bottles labelled with the same number as the tubes. More bisulphide of carbon is then added, the sediment thoroughly mixed with it by means of an iron rod, which is afterwards washed off with the solvent, and the tubes again placed in the centrifugal and run ten minutes. The decanting is repeated into the correction bottle, more solvent added as before, and the tubes swung a third time. The third decantation usually leaves the residue free from any amount of bitumen which would influence the results. The tubes are placed in a warm spot to volatilize the remaining solvent and when dry are weighed. In the meantime the bisulphide of carbon solution is burned for a correction, as in the analysis of refined asphalts, and the weight added to that of the tube. The loss of weight of the tube gives the percentage of bitumen in the cement.

An excellent power centrifuge holding six tubes which is driven by electricity is furnished by the American Name Plate Company, 62 Sudbury Street, Boston, Mass.

Change in Consistency of Asphalt Cements on Maintaining in a Melted Condition.—This change can be found by heating some of the cement to any desired temperature, as in the determination of loss at 325° F. in fluxes and making penetrations before and after heating.

This treatment, however, is much more severe than any that a cement would ever receive at a plant, as the surface, as compared to the volume under treatment, is very much larger than is the case in a melting-kettle or dipping-tank. Such determinations are, in consequence, of relative value only in comparing cements made with different fluxes.

Mineral Aggregate.—The mineral aggregate is determined in the same manner as in solid bitumens.

Examination of the Finished Surface Mixture.—Samples of surface mixture are examined as to the per cent of bitumen they contain and the grading of the mineral aggregate.

Bitumen.—The amount of bitumen is determined in one of two ways:

1. A funnel, 2½ inches in diameter, with a short stem, is placed in a conical flat-bottom assay flask, holding about 250 c.c. A Schleicher & Schüll 9 cm. 597 filter-paper is folded and placed in the funnel. Ten grams of the surface mixture are weighed out

in fair-sized pieces on the balance to be described later and placed upon the filter. With a washing-bottle provided with two tubes through its cork, one reaching to the bottom of the bottle and the other only just passing the cork, but with a capillary orifice, a small stream of bisulphide of carbon can be delivered on inverting the flask without the necessity of using pressure from the mouth and inhaling the noxious vapor of the solvent. With this bottle a fine stream is directed on the surface mixture, but no more than it can absorb. It is allowed to stand until it has softened and settled upon the filter. The latter is then filled up to an eighth of an inch below the rim and the funnel covered with a 2½-inch watch-glass. It is not filled up at first, as before the mixture has been softened and settled upon the paper the solvent would have run through the filter-paper and would not have been used economically. As the percolation goes on the solvent is renewed, and if it goes too slowly the rate may be hastened by washing between the paper and the funnel with bisulphide, which will dissolve the bitumen, which may have hardened and closed the pores by evaporation, or by lifting the filter a little and letting it drop back. On the day the analysis is started the sand is washed as clean as possible, but nothing more is done. The filter with the sand and the percolate is allowed to stand overnight to permit anything that has run through to settle out.

In the morning the funnel is placed in a clean assay flask and the percolate is carefully decanted into a correction bottle, being careful not to disturb the sediment.

Some bisulphide of carbon is poured on this, it is shaken up and poured back on the filter, the first assay flask being thoroughly cleaned with a feather and everything brought upon the original filter-paper. The mineral aggregate is washed clean with the solvent.

The percolate, or solution of bitumen, in bisulphide of carbon is poured from the correction bottle into a dish, burned, ignited, and the correction obtained.

In the meantime the mineral aggregate after drying is separated from the filter over a piece of glazed paper by scraping with a blunt spatula or rubbing between the fingers in an appropriate way until all the mineral matter that can be removed is separated, taking care, of course, not to detach any fibres of the paper. It is then dusted into a weighed No. 2 Royal Berlin porcelain crucible and set aside. The filter-paper, containing much fine mineral matter in its pores, is burned either with the correction in its dish or in any satisfactory way, its ash and the correction added to the mineral aggregate and the crucible's entire contents, after one is assured that no trace of solvent remains, is weighed. The difference in the weight of the aggregate and the ten grams of surface taken is that of the bitumen and gives the per cent of bitumen in the mixture, which should be calculated to the nearest tenth of one per cent. The expression of the percentage in hundredths is beyond the limit of accuracy of the method and is cumbersome and unnecessary.

Centrifugal Method for the Examination of Surface Mixture.—In laboratories where large numbers of surface mixtures are examined daily, as in that of the author, where the number has reached 70, the centrifugal method as described on page 570 is commonly used. Ten grams of the surface mixture are weighed out in a glass tube and submitted to the same treatment as is applied to asphalt cements. The loss of weight of the tube minus that of the correction obtained on burning the extracted bitumen gives the percentage of bitumen in the mixture. Should the mineral aggregate contain coal or other material too light to be thrown out by centrifugal action, the decanted bisulphide must be filtered before burning or the percolation method alone can be used.

Grading of the Mineral Aggregate in a Surface Mixture.—The mineral aggregate from the porcelain crucible after having been weighed for the determination of bitumen or the mineral matter from the glass tube which has been submitted to the centrifugal process is emptied upon the 200-mesh sieve. The particles of dust, which are caked together, are broken up by gentle pressure with the finger tips and the coarser sand grains thoroughly cleaned by attrition. When nothing further passes the sieve the residue is transferred in any convenient way to the pan of a balance, preferably one which, while weighing accurately to a hundredth of a gram or one-tenth per cent of the amount of surface mixture taken, does not require the use of weights but can be rapidly manipulated.

Such a balance is supplied by the C. H. Stoelting Co., 31 W. Randolph St., Chicago, Ill., or Eimer & Amend, New York, in the Chaslyn balance, Fig. 39. This is a beam balance, very much of the Westphal specific gravity type, which weighs readily to 10 mgs. by moving rings of different weight along the beam. It is exactly suited for rapid work with surface mixtures where results no closer than $\frac{1}{10}$ of 1 per cent are sought. With this balance the weight of the residue on the 200-mesh sieve is obtained and the difference between this and the weight of the mineral aggregate gives the percentage of 200-mesh material and filler in surface mixture. It is a determination by loss, and so no effort is necessary to save the dust which passes the sieve, unless it is desired to determine its chemical nature or subdivide further by elutriation when it should be caught in a closely fitting pan.

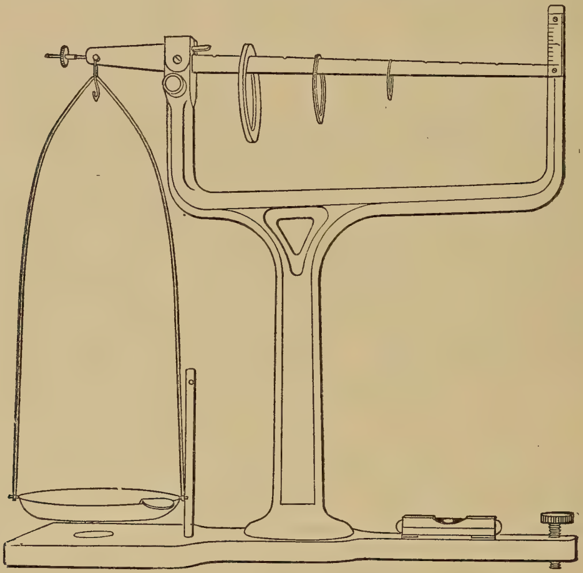

Fig. 39.—Chaslyn Balance.

The other sieves are used in succession after the 200-mesh with the precautions mentioned under sands and the percentages passed by each determined.

The percentage of bitumen, dust, or filler, and various sized sand should amount to 100 per cent.

The results are reported on the following form:

NEW YORK TESTING LABORATORY,

Maurer, N. J.,..........................

Mesh composition and quality of..................................

Received from..

Test No........... Sample No...........

Test No........... Sample No...........

Test No........... Sample No...........

Test No........... Sample No...........

Test No.												
Standard Mixture.				Mesh No.	Per Cent.		Per Cent.		Per Cent.		Per Cent.	
Heavy Traffic		Light Traffic			Passing	Total	Passing	Total	Passing	Total	Passing	Total
10.5		10.0		Bit.								
13.0		10.0		200								
13.0	26.0		18.0	100								
13.0				80								
24.0				50								
11.0				40								
8.0	16.0		24.0	30								
5.0				20								
3.0				10								
		On		10								

Penetration of A. C...

Pat paper stain. ....

Remarks:

Method for the Examination of Asphaltic Concrete and Asphalt Blocks.—The quantity of concrete which should be taken for the analysis will depend upon the size of the largest particles of the mineral aggregate.

Three hundred grams of an asphalt block, 500 grams when the largest particles range from ½ to ¾ inch, or 1000 grams when 1 inch particles predominate, will be sufficient. Several comparative analyses of the latter class, employing respectively, 1, 2, and 10 kilos of the sample, were in very close agreement.

In order to retain the original relation of the various particles of the mineral aggregate, it is obvious that none of the stones should be fractured in taking the portion for analysis, and the sample should accordingly be softened by heating so that it may readily be broken apart by hand.

Analysis by Decantation.—An appropriate amount of the sample is placed in a metal beaker or measure, covered with carbon disulphide and allowed to settle for two hours; decant and cover with fresh carbon disulphide; repeat this treatment until the solution becomes clear.

Burn off the carbon disulphide to recover the mineral matter carried over with the extract, in a platinum or porcelain dish. Dry and weigh residue together with the correction. The loss from weight of concrete taken is bitumen.

The mineral aggregate may now be further examined by carefully compacting in a suitable vessel to determine the amount of voids or sifted through a series of perforated metal and wire cloth screens to ascertain the size of the various particles or its grading.

Centrifugal Method.—While the preceding method is not lacking in accuracy, when intelligently manipulated, it is far from rapid, especially when a large mass of material is under consideration, and more or less extravagant in the use of solvent. The following method has therefore been developed, applying the essentials of the special centrifugal extractor as closely as they could be gathered from a brief verbal description, very kindly supplied by its ingenious inventor, Mr. August E. Shutté.

The body of the apparatus consists of a double walled iron casting, the inside dimensions of which are 9¼ inches diameter by 7 inches deep, set upon three legs and provided with a tightly fitting cover carrying a reservoir, also consisting of a single casting. The combined portions form in effect a large Soxhlet extractor, as will be observed upon inspection of the illustrations, Figs. 40 and 41.

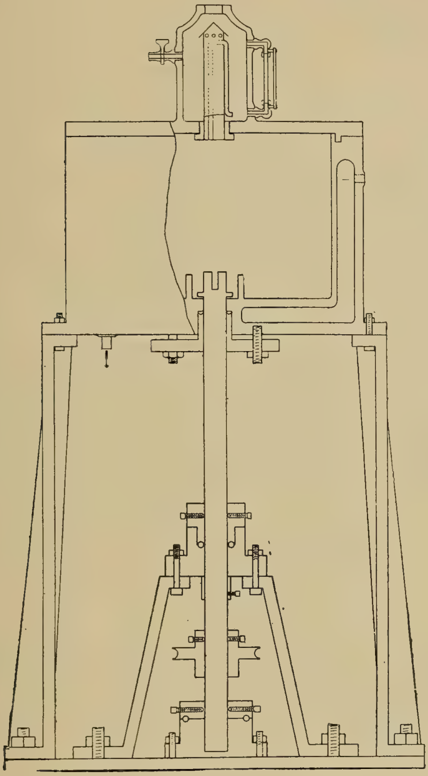

Fig. 40.

A slotted shaft extends through the bottom of the extractor and a gland is provided for making a tight joint. This, as well as the gasket under the cover, may be packed with ball lamp wicking and soap.

The sample is broken down as finely as practicable and placed on the cast iron plate which fits upon the end of the slotted shaft. A filter ring cut from No. 80 soft roofing felt about .090 inches thick is placed under the rim of the dome, which is now bolted down hard upon the plate over the sample. Fig. 42.

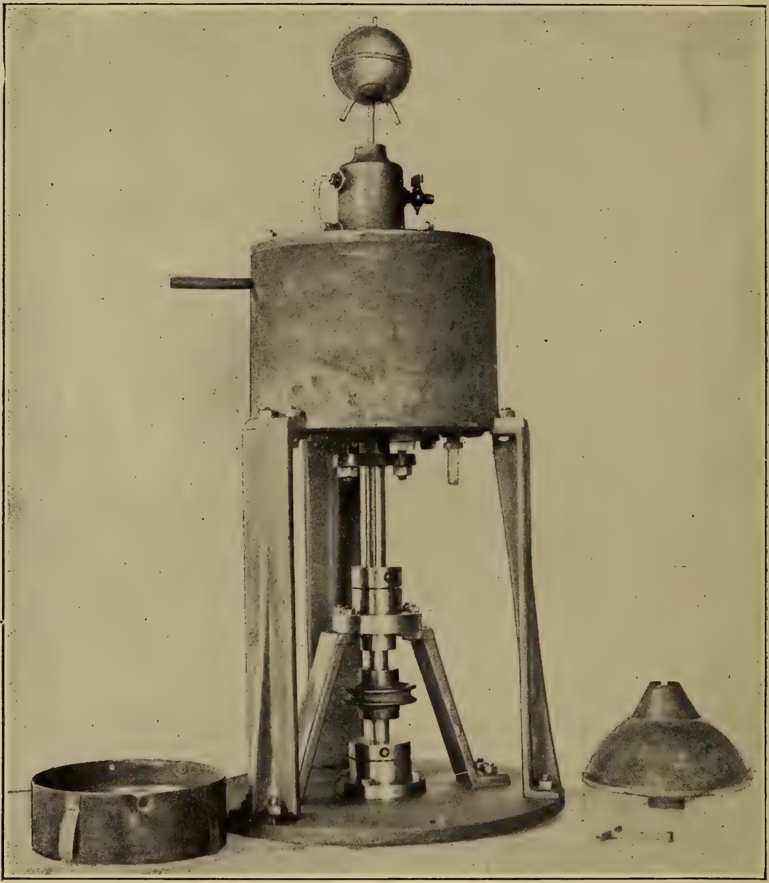

Fig. 41.

A dome 8 inches diameter by 3¼ inches high, spun out of No. 16 brass, will accommodate one kilogram of concrete. The plate is

8¼ inches diameter. The bolt should be tool steel, $\frac{3}{16}$ inch diameter. A shallow brass pan is placed in the device to receive the extract as it is thrown out of the revolving dome.

The dome having been placed in position upon the shaft, about 300 cc. carbon disulphide is poured upon the sample through the perforations in the top and the apparatus closed.

Steam is turned into the lower jacketed body and cold water through the condenser. After allowing a few minutes to become warm, the dome is revolved at a rate of from 1500 to 1800 R. P. M. by any suitable power, and as the solvent carrying the bitumen is thrown out into the receiving pan, it is volatilized and passes into the reflux condenser, falling back into the reservoir on the cover. When about 250 cc. has accumulated, it is automatically syphoned back into the dome upon the sample as fresh solvent.

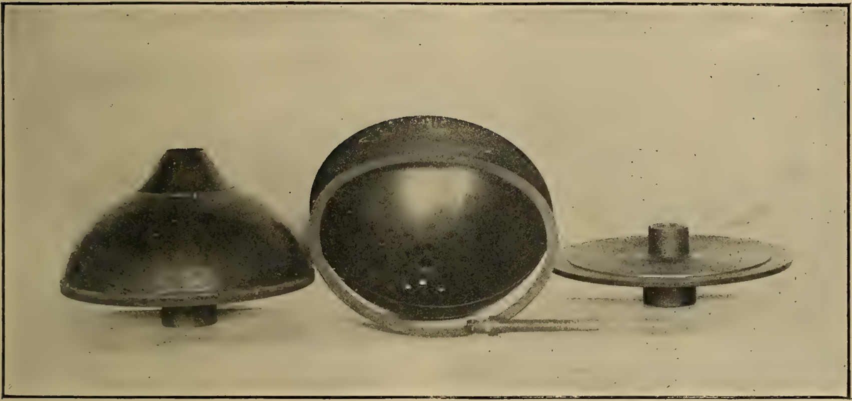

FIG. 42.

As but three minutes are required to swing the sample dry, it is not necessary to revolve the dome continuously; stop it after this period of time and do not start again until the gauge glass on the reservoir indicates that a fresh portion of solvent has passed over upon the sample.

About four treatments are sufficient for a kilogram sample, after which the flow of steam is discontinued and cold water reversed through the jacket to hasten cooling.

The bitumen free from all but minute traces of the finest portion of the mineral aggregate, which may be disregarded, will be found in the pan, while the clean aggregate is allowed to dry spontaneously and then weighed, the bitumen being determined by difference. It is examined further as desired, by sifting, etc., as previously described.

The entire extraction may thus readily be completed in less than an hour, with little loss of solvent.

In handling asphalt block mixtures employing 300 grams of sample and but three portions of cold carbon disulphide, an extraction may be made in about twenty minutes. In the latter case, the solvent is recovered in a separate distilling apparatus arranged to receive the pan holding the extract directly, or an accumulation is worked over at convenient times.

Density and Voids in Surface Mixtures.—The density which a surface mixture can attain on compaction is often a source of information as to its quality, and from this the voids in the compacted material can be calculated. The mixture is compressed in a mould made for the purpose. This should consist of a base 8 inches long, 5 inches wide and 3⅜ inches high. On top of this base are found a cylindrical boss or post 1¼ inches in diameter and 1 inch high, and a hole of the same or a little larger diameter, opening into a hollow in the base. A hollow cylindrical mould or sleeve of steel of the same internal diameter as the boss and 3½ inches high is provided and a solid plunger of steel to fit this accurately. About......grams of the surface mixture is heated in a deep iron dish to 325° F., the cylinder and plunger being also heated. The cylinder is placed over the post and filled with the hot mixture and compressed with the plunger and sharp blows of a heavy hammer, or better in any suitable press such as the Riehle or Olsen tensile and crushing power machines. When ultimate compression has been attained in this way the cylindrical mould is removed from the boss and turned over or reversed and again placed on the boss. The space formerly occupied by the boss now gives an opportunity for the insertion of the plunger and compression of the cylinder of asphalt mixture from the other end. Finally, the mould is placed over the opening in the base and the cylinder of surface knocked out with a few blows of the plunger. It should be between 1 and 2 inches long.

Its density can be determined by weighing it in air and water, but the quickest way is to measure its length with calipers to .01 inch and find its volume in cubic centimeters by reference to the table on page 582.

The weight of the cylinder divided by the volume gives the density. This should not fall below 2.20 for good mixtures, made with quartz sand. The voids in such a cylinder can be calculated from the known proportions and density of the materials of which it is composed, as can be seen from the following example:

The customary surface mixtures consist, in parts by weight, of:

Sand	75%
Dust	10
Trinidad asphalt cement	15
	100%

By volume this would be, the density of the sand being 2.65, that of dust 2.60, and that of the asphalt cement 1.25:

Sand	75/2 65	28.30	or	64.10
Dust	10/2.60	3.85	"	8.72
Asphalt cement	15/1.25	12.00	"	27.18
		44.15		100.00

The cement in use, being 27.18% of the entire volume of the mixture, will fill the voids which ordinarily exist in the mineral aggregate if the mixture receives its ultimate compression and density. If the voids are larger it will be too little and some voids will remain unfilled; if they are smaller it will be too much and will make the surface too yielding.

Considering the proportions given as being theoretically correct, the density of the resulting mixture, when it receives its ultimate compression, should be:

64.1	vols. at 2.65 density	1.699
8.7	" " 2.60 "	.226
27.2	" " 1.25 "	.340
100.0		2.265

TABLE FOR DETERMINING CONTENTS IN CUBIC CENTIMETERS OF CYLINDERS 1.25 INCHES IN DIAMETER AND VARIOUS HEIGHTS IN INCHES.

Height, Inches.	Cubic Inches.	Cubic Centimeters.	Height, Inches.	Cubic Inches.	Cubic Centimeters.
.95	1.17	18.17	1.48	1.81	29.66
.96	1.18	19.34	1.49	1.83	29.99
.97	1.19	19.50	1.50	1.84	30.15
.98	1.20	19.66	1.51	1.85	30.32
.99	1.22	19.99	1.52	1.86	30.48
1.00	1.23	20.16	1.53	1.87	30.64
1.01	1.24	20.32	1.54	1.89	30.97
1.02	1.25	20.48	1.55	1.90	31.14
1.03	1.26	20.65	1.56	1.91	31.30
1.04	1.28	20.98	1.57	1.93	31.63
1.05	1.29	21.14	1.58	1.94	31.79
1.06	1.30	21.30	1.59	1.95	31.95
1.07	1.31	21.47	1.60	1.96	32.12
1.08	1.33	21.79	1.61	1.98	32.45
1.09	1.34	21.96	1.62	1.99	32.61
1.10	1.35	22.12	1.63	2.00	32.77
1.11	1.36	22.28	1.64	2.01	32.94
1.12	1.37	22.45	1.65	2.02	33.09
1.13	1.39	22.78	1.66	2.04	33.42
1.14	1.40	22.94	1.67	2.05	33.59
1.15	1.41	23.11	1.68	2.06	33.76
1.16	1.42	23.27	1.69	2.07	33.92
1.17	1.44	23.60	1.70	2.09	34.25
1.18	1.45	23.76	1.71	2.10	34.41
1.19	1.46	23.92	1.72	2.11	34.58
1.20	1.47	24.08	1.73	2.12	34.74
1.21	1.48	24.25	1.74	2.14	35.07
1.22	1.50	24.58	1.75	2.15	35.23
1.23	1.51	24.74	1.76	2.16	35.40
1.24	1.52	24.91	1.77	2.17	35.56
1.25	1.53	25.07	1.78	2.19	35.89
1.26	1.55	25.40	1.79	2.20	36.05
1.27	1.56	25.56	1.80	2.21	36.21
1.28	1.57	25.73	1.81	2.22	36.38
1.29	1.58	25.89	1.82	2.23	36.54
1.30	1.60	26.22	1.83	2.25	36.87
1.31	1.61	26.38	1.84	2.26	37.03
1.32	1.62	26.55	1.85	2.27	37.20
1.33	1.63	26.71	1.86	2.28	37.36
1.34	1.65	27.04	1.87	2.29	37.53
1.35	1.66	27.20	1.88	2.31	37.85
1.36	1.67	27.35	1.89	2.32	38.02
1.37	1.68	27.53	1.90	2.33	38.18
1.38	1.69	27.69	1.91	2.34	38.35
1.39	1.70	27.86	1.92	2.36	38.67
1.40	1.72	28.18	1.93	2.37	38.84
1.41	1.73	28.35	1.94	2.38	39.00
1.42	1.74	28.51	1.95	2.39	39.16
1.43	1.75	28.68	1.96	2.41	39.49
1.44	1.77	29.00	1.97	2.42	39.66
1.45	1.78	29.17	1.98	2.43	39.82
1.46	1.79	29.33	1.99	2.44	39.98
1.47	1.80	29.50	2.00	2.45	40.15

The density of the compacted mixture is usually found to be not over 2.22, and at this figure there would be about 2 per cent of voids. At a density of 2.18 the voids would reach 3.7 per cent.

The density of coarse mixtures, such as asphalt blocks or asphaltic concrete, may be determined by compressing the hot mixture in a mold of appropriate size under suitable pressure in a power press.

Asphalt blocks are weighed as received, first in air and then in water, in the most convenient manner, and the density calculated from the data thus obtained.

The specific gravity of the mineral aggregate in such mixtures is most conveniently determined in a Jackson's apparatus, previously referred to.

Water Absorption of Surface Mixtures.—Cylinders prepared as previously described, or, if such a mould is not at hand, compressed to the best possible extent in an ordinary diamond mortar, are weighed in air and then suspended by a horsehair and immersed in distilled water at ordinary temperature and again weighed, while still immersed in water and suspended by the hair in the same way, at intervals of 1, 2, 7, 15 days and one month. The gain in weight shows the water absorbed, which is calculated to milligrams per square centimeter, or inch, or pounds per square yard, as may be desired, by determining from its dimensions the number of square inches of surface the cylinder has.

Where cylinders are of such density that the surface is but slightly acted upon by water and there is no disintegration, they may be carefully wiped off and weighed directly.

An example of the amount of water absorbed by a good mixture is seen in the following determinations:

GAIN IN GRAMS PER SQUARE INCH AND POUNDS PER SQUARE YARD OF TRINIDAD SURFACE MIXTURE FROM THE LONG ISLAND CITY PLANT OF THE BARBER ASPHALT PAVING COMPANY.

Height of cylinder.	1.15 inches
Diameter.	1.25 "
Surface.	6.97 square inches

Interval After Immersion.	Mgs. Per Square Inch.		Pounds Per Square Yard.
	Gain in Interval.	Total Gain.	Total Gain.
24 hours	.0169		
48 "	.0021	.0190	.0540
7 days	.0092	.0282	.0803
15 "	.0045	.0327	.0930
28 "	.0035	.0362	.1031[1]

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[1] See also pages 465 and 468.

TABLE FOR DETERMINING SQUARE INCHES OF SURFACE IN CYLINDERS 1.25 INCHES IN DIAMETER AND VARIOUS HEIGHTS IN INCHES.

Height.	Square Inches.	Height.	Square Inches.	Height.	Square Inches.
1.00	6.38	1.28	7.48	1.65	8.93
1.10	6.77	1.30	7.56	1.68	9.05
1.11	6.81	1.33	7.68	1.70	9.13
1.12	6.85	1.35	7.76	1.73	9.25
1.13	6.89	1.38	7.87	1.75	9.33
1.14	6.93	1.40	7.95	1.78	9.45
1.15	6.97	1.43	8.07	1.80	9.52
1.16	7.01	1.45	8.15	1.83	9.64
1.17	7.05	1.48	8.27	1.85	9.72
1.18	7.08	1.50	8.34	1.88	9.84
1.19	7.13	1.53	8.46	1.90	9.92
1.20	7.17	1.55	8.54	1.93	10.03
1.21	7.21	1.58	8.66	1.95	10.11
1.22	7.24	1.60	8.74	1.98	10.23
1.25	7.36	1.63	8.86	2.00	10.31

$$\frac{\text{Weight of water in pounds}}{\text{Surface of cylinder in square inches}} \times 2.85 = \text{pounds absorbed per square yard.}$$

Other Physical Tests.—Other physical tests of surface mixtures are made at times, such as determination of tensile and compression strength, shearing tests, ductility of cements at various temperatures, abrasion, etc., but as they are only done for special purposes they need not be described here. It may be said, however, that it should be possible to rub together wet cylinders of any mixture without detaching particles of the mineral aggregate, and that if this cannot be done such a mixture will not be capable of withstanding cold, wet weather.

Old Street Surfaces.—Old street surfaces are frequently examined to determine their composition, the percentage of bitumen and the grading of the mineral aggregate, the consistency of the bitumen they contain, their density and their power to resist water. All these determinations are made according to methods already described with almost no modifications except that the material should be carefully dried. Enough surface mixture is extracted alongside a standard check cement to furnish the same amount of bitumen, a piece of surface is shaped to such a form for the water absorption test that its superficial area can be calculated and the nature of the aggregate, sand and filler, may be as carefully examined as a new mixture made with known materials.

Determination of the Consistency of the Bitumen in Paving Mixtures.—Where no sample of the asphalt cement which has been used in making a surface mixture is available for the determination of its consistency this can be arrived at very closely by proceeding as directed for the preparation of pure bitumen on page 547.

Modification of Methods.—The preceding methods are such as are in use in the paving industry at the present time; but they are, of course, subject to change and improvement from time to time.

Impact Tests for Toughness of Asphalt Surface Mixture.—This test is made with the machine devised for the purpose of testing the toughness of rocks by Mr. Logan Waller Page, of the Office of Public Roads, U.S. Department of Agriculture, and described in Bulletin No. 79, Bureau of Chemistry, U. S. Department of Agriculture, page 33, on cylinders 1¼ inches in diameter and 1 inch high and weighing about 50 grams. The cylinders are prepared by compressing sufficient of the hot surface mixture, at an appropriate temperature, in the steel mould previously described for the preparation of test pieces for density. In this way a density of the cylinder from 2.2 to 2.3 can readily be attained. When the cylinders are cooled they are brought to a normal temperature of 40, 78, and 100° F., and tested to the breaking point in the machine, that mixture being, of course, the toughest which withstands the most blows.

Mr. Page describes the manner of making the test as follows:

"This test is made on cylinders with an impact machine especially designed for the purpose. Instead of a flat end plunger resting on the test-piece as in the cementation test, a plunger with the lower and bearing surface of spherical shape, having a radius of 1 cm. (0.4 inch) is used. It can be seen that the blow as delivered through a spherical-end plunger approximates as nearly as practicable the blows of traffic. Besides this, it has the further advantage of not requiring great exactness in getting the two bearing surfaces of the test-piece parallel, as the entire load is applied at one point on the upper surface. The test-piece is adjusted so that the center of its upper surface is tangent to the spherical end of the plunger, and the plunger is pressed firmly upon the test-piece by two spiral springs which surround the plunger guide-rods. The test-piece is held to the base of the machine by a device which prevents its rebounding when a blow is struck by the hammer. The hammer weighs 2 kg. and is raised by a sprocket chain and released automatically by a concentric-electromagnet. The test consists of a 1 cm. fall of the hammer for the first blow, and an increase fall of 1 cm. for each succeeding blow until failure of the test-piece occurs. The number of blows required to destroy the test-piece is used to represent the toughness."

Indentification of Bitumens.—It is often necessary to identify the source of a solid bitumen or of a flux, or of a mixture of two or more of these. In order to accomplish this a complete determination of the physical characteristics and proximate chemical composition of the bitumen should be first carried out. If the data thus obtained are not such as to identify the material, especially in the case of asphalt cements, an examination of the character of the mineral matter that is present may assist in forming an opinion in regard to the origin of the solid bitumen that is present, the ash being more or less characteristic of the source from which the bitumen is derived. For example, the ash in Trinidad asphalt is characterized by a light pink color and, on microscopic examination, is found to contain very sharp particles of quartz with fine clay colored by the oxide of iron which is present. If an ash of this description is not detected it will be safe to say that the material contains no Trinidad asphalt. Some Cuban asphalts have a somewhat similar ash, but confusion cannot arise if they are compared microscopically with one obtained from a known sample of Trinidad asphalt.

If the extremely fine mineral matter which remains in suspension in carbon disulphide, which is obtained in a correction in the course of analysis, is examined, this will also be found to be characteristic.

If the bitumen under examination contains but a small percentage of ash and this consists of not excessively fine mineral particles, it may be assumed that a solid native bitumen is present and that the material is not composed entirely of a residual pitch. The residual pitches yield but traces of mineral matter and this is extremely fine, usually ferruginous, and derived from the stills in which the distillation has been carried on.

Gilsonite is so extremely pure that its mineral matter can only be differentiated from that of residual pitch from the fact that it is not so red in color.

The fixed carbon which the bitumen yields on ignition is a very important factor in fixing its origin. A very high percentage points to a grahamite. The residual pitch from Texas oil yields more fixed carbon than those from California oils. The asphalts, generally, yield from 10 to 15 per cent of fixed carbon. The fixed carbon yielded by asphalt cements may be compared with that of cements of known origin.

The proportion of the bitumen soluble in 88° naphtha which is attacked by sulphuric acid, according to the method which has been described, will differentiate bitumens such as gilsonite and mixtures containing large proportions of it from those made with asphalts. The same determination will differentiate the California fluxes from those made from Texas oil, although this may be generally arrived at from the difference of the specific gravity of the two materials and by the fact that the Texas oil contains about one per cent of paraffine scale.

Other determinations which have been made in the course of the general analysis will have their value in special cases, and the methods may be applied according to the judgment of the analyst.

It may be noted that none of the true asphalts contain bitumen insoluble in cold carbon tetrachloride which is soluble in carbon disulphide.

CHAPTER XXIX.

SOLVENTS.

Bitumen, as has appeared in the preceding pages, is entirely or partially dissolved by very many solvents, and the relative solubility in the different ones has been used as a means of differentiating them. Analysts are not, however, agreed as to the most suitable solvents to use for this purpose.

For the determination of total bitumen bisulphide of carbon is generally employed, but chloroform and oil of turpentine have also been used for this purpose. One analyst uses naphtha of 74° B., boiling between 40° and 60° C., another both 88° and 62° B. naphtha; while others have used acetone and ethyl ether as solvent for the malthenes. It is of interest to determine what there is in favor of the different solvents and what there is against them.

Chloroform.—Chloroform is a most excellent solvent for bitumen and might, perhaps, be used for making the determination of total bitumen were it not for certain disadvantages. In a pure form it is extremely expensive, costing $1.00 per pound. Commercial chloroform is not sufficiently pure to be used as a solvent, as can be seen from the following determinations:

BOILING-POINT.

	Temperature.	Per Cent Distillate.
Pure chloroform.	61.2° C.	
Commercial chloroform	55° to 60° C.	5.7%
. . . .	60° " 62° C.	92.9
. . . .	Residue	1.4
		100.0

From these figures it is evident that the commercial chloroform contains at least 10 per cent of impurities, the amount of which is not constant, and it is, therefore, not suitable for use as a solvent for bitumen. Chloroform possesses the additional disadvantage of evaporating much more slowly than bisulphide of carbon; and, as it is non-inflammable, it cannot be burned off rapidly in determining the correction for the mineral matter, as is the case with bisulphide of carbon. For these reasons it is not probable that it will ever be adopted as a standard solvent.

Oil of Turpentine.—Oil of turpentine is not a definite compound. It boils between 97° and 160° C., the greater portion passing over between 155° and 160° C. It is an artificial product, having no constant composition, and is, therefore, unsuitable for use as a standard solvent.

Bisulphide of Carbon.—Bisulphide of carbon for many reasons is the best solvent for the determination of total bitumen. Objection has been raised against it because a slight amount of bitumen, which is dissolved by chloroform and turpentine, is not soluble in it, but for technical work at least it is entirely satisfactory. It possesses the great advantage that, if redistilled, it is very pure, with a constant boiling-point of 46° C. and specific gravity 1.27. It is the cheapest solvent for total bitumen that is available, as it can be brought in thousand-pound lots at six cents per pound or practically free from sulphur at 8 cents, and it has not been found necessary for ordinary bitumen determinations to redistil this material. It will undoubtedly be adopted as the standard solvent for the purpose for which it is used.

Carbon Tetrachloride.—For the asphalts and some of the native bitumens carbon tetrachloride may be substituted for bisulpide of carbon; but, as has appeared in previous pages, in certain cases it does not dissolve all the bitumen which is soluble in the latter solvent. On this account it is never used for the determination of total bitumen, but only to discover the percentage of bitumen which is soluble in bisulphide of carbon, which it does not dissolve, as a means of differentiating the amount of material which has been injured by natural weathering or overheating, for which purpose it is extremely useful. The specific gravity of the pure carbon tetrachloride is 1.604 at 15° C., but the commercial supply often contains sufficient bisulphide of carbon to lower this. Bisulphide of carbon can be largely removed by blowing a current of air through the solvent or by distilling it with a Young dephlegmator[1] until the boiling-point reaches 76.6° C. The best carbon tetrachloride found on the market was that furnished by the Acker Process Company, Niagara Falls, N. Y. This had a density of 1.604, whereas inferior supplies may fall as low as 1.593. This concern has, however, gone out of business, and the less pure and more expensive German product must now be used after redistillation.

Ethyl Ether.—No objection can be raised to the use of ether for the determination of malthenes if the purest product made by Squibb is used. The cost of this is, however, prohibitive in a laboratory where any large amount of work is carried on. Commercial ether is too impure and too irregular in composition to be used for the purpose; it contains alcohol and water. The use of ether as a solvent must, therefore, be abandoned.

Acetone.—The acetone found on the market under the designation "chemically pure" is of fairly constant boiling-point, that of the pure material being 56.5° C.

BOILING-POINT.

Temperature.	Per Cent Distillate.
56° to 57° C.	26.6%
57° " 58° C.	58.4
58° " 59° C.	9.0
59° " 60° C.	4.0
Residue	2.0
	100.0

This solvent is, like ether, very expensive, 50 cents per pound, and its general use is prohibited by this fact.

Commercial acetone, costing $1.75 per gallon, is quite unsuitable for use as a solvent owing to its lack of purity and uniformity. A specimen distilled in the author's laboratory gave the following fractions:

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[1] J. Chem. Soc., 1899, 75, II, 699.

BOILING-POINT.

Temperature.	Per Cent Distillate.
56.8° to 57° C.	2.9%
57° to 58° C.	13.7
58° " 59° C.	32.2
59° " 60° C.	15.4
60° " 61° C.	9.1
61° " 62° C.	4.8
62° " 63° C.	4.8
63° " 64° C.	2.9
64° " 65° C.	2.4
65° " 70° C.	4.3
70° " 75° C.	3.3
75° " 80° C.	2.2
Residue	2.0
	100.0

It is evident that the commercial material consists largely of substances boiling at higher temperature than pure acetone. It will, for the reasons given, never be used as a standard solvent.

Light Petroleum Distillates.—Light petroleum distillates have been very generally used for the separation of the softer constituents of the solid bitumens, but different analysts have used it of various boiling-points and densities. None of these solvents consists, of course, of any one hydrocarbon; they are mixtures chiefly of isopentane, pentane, isohexane, hexane, isoheptane, heptane and the octanes in 62° naphtha, together with small percentages of other hydrocarbons such as methylene, pentamethylene and hexamethylene, but the amounts of the latter are too small to have any bearing upon the solvent power. The boiling points of the principal constituents of the naphthas are, according to Young:[1]

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[1] J. Chem. Soc., 1898, 73, II, 906.

BOILING-POINTS.

Name.	760 Millimeters.
Isopentane	28° C.
Pentane	36° C.
Pentamethylene	50° C.
Isohexane	61° C.
Hexane	69° C.
Methylpentamethylene	72° C.
Benzene	80° C.
Hexamethylene	81° C.
Isoheptane	90° C.
Heptane	98° C.
Methylhexamethylene	102° C.
Toluene	111° C.
Octane	125° C.

On fractioning a naphtha of 88° Beaumé density with a Young dephlegmator of eighteen sections the following results were obtained:

BOILING-POINT.

Temperature.	Per Cent of Distillate.	Specific Gravity 20° C/20° C.
25° to 30° C.	21.5%	.6287
30° " 35° C.	8.8	.6324
35° " 40° C.	12.7	.6287
40° " 45° C.	13.6	.6317
45° " 50° C.	11.2	.6448
50° " 55° C.	5.6	.6589
55° " 60° C.	4.8	.6539
60° " 65° C.	8.8	.6566
65° " 70° C.	3.2	.6673
Residue	9.8	.7027
	100.0	

It is evident from the above figures that this naphtha is far from being composed of a single hydrocarbon. It contains a preponderance of iso- and normal pentanes and isohexane, but it would require a very large number of fractionations[1] with the most perfect form of dephlegmator to obtain a single hyrdocarbon or even a mixture of pentanes. One distillation, with no definite specifications of the method, would have little or no effect; and, in practice, it has not been found to result in any improvement of the naphtha as a solvent commensurate with the trouble involved. The same is the case with 74° and 62° Beaumé naphtha. The least dense of these naphthas consists of a mixture of hydrocarbons, the most prominent of which are the hexanes, the more dense one containing heptanes and octanes. The author, therefore, considers it necessary to merely see that the density of every lot of naphtha in use should be a standard one, such as .7290 for 62° Beaumé, .6863 for 74° Beaumé, and .6422 for 88° Beaumé. If the lot in hand is denser than the standard it must be rejected, but if it is lighter it can be brought to the standard, in the case of the 88° Beaumé solvent, by blowing with a current of air for a short time, or in the heavier ones by distillation. The solvent power in this way will be found to be quite as uniform among different lots as if a single fractionation was attempted.

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[1] See Young, "Fractional Distillation," Macmillan & Co., 1903.

It remains to determine whether there is a preference for one density of naphtha over another. If one alone is to be used that of 74° Beaumé may be well accepted as being a solvent of medium power, but the author has found that the use of both 88° and 62° Beaumé naphtha is most desirable, as in this way a more thorough differentiation can be accomplished.[1]

From the preceding data it would seem that the desirable solvents for use in the asphalt-paving industry are those which have been mentioned in the chapter on Methods of Analysis; bisulphide of carbon for the total bitumen, carbon tetrachloride for the detection of bitumen which has been affected by overheating or weathering, and 88° and 62° Beaumé naphtha for the purpose of determining whether a bitumen shows a normal relation between the amounts dissolved by these two solvents or points to the addition of a flux to an extremely hard asphalt.

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[1] See page 542.

CHAPTER XXX.

EQUIPMENT OF A LABORATORY FOR CONTROL OF ASPHALT WORK.

For making the necessary determinations for the control of the materials and mixtures in use in the construction of an asphalt pavement, according to the methods which have been outlined in a previous chapter, no elaborate laboratory is necessary. Sub-laboratories for this purpose have been established economically by the author at many plants under his control.

The room which is to be used need not be large, but should be well lighted. It should contain several tables securely fastened to the wall. That upon which the balance and penetration machine are to be placed should be as free from vibration as possible.

The equipment usually supplied for such a laboratory consists of the following pieces of apparatus:

1	Chaslyn balance	$15 00
2	Bunsen burners, No. 2597, Eimer & Amend, New York	2 00
1	Fairbanks sand scale, No. 485, Fairbanks Co., New York	6 00
1	set of sieves (200, 100, 80, 50, 40, 30, 20, 10 mesh)	15 75
1	New York Testing Laboratory Penetrometer, Howard & Morse, 1197 DeKalb Avenue, Brooklyn, N. Y.	60 00
2	thermometers for penetrometer, C. J. Tagliabue Co., N. Y.	2 50

1 doz. 2½″ glass funnels, E. & A. No. 3345	1 20
1 doz. watch glasses to cover funnels, E. & A. No. 7189	56
1 doz. Erlenmeyer flasks, Jena glass, 200 cc., E. & A. No. 3863	1 68
½ doz. 4¼″ porcelain evaporating dishes, E. & A. No. 2963	2 70
½ doz. watch glasses to cover dishes, E. & A. No. 7189	75
½ doz. Royal Berlin porcelain crucibles, No. 0, without covers, E. & A. No. 2850	1 38
4 Royal Berlin porcelain crucibles No. 2, without covers, E. & A. No. 2850	1 40
4 packages filter paper, S. & S. No. 597, E. & A. No. 3213 (3½″)	1 00
1 glass cylinder, graduated to 100 cc., E. & A. No. 2919	70
½ doz. flat bottom sample tubes, 4″ high by ⅝″ diameter, E. & A. No. 4647	30
1 pair tongs, E. & A. No. 2883-B	85
2 iron ring stands, E. & A. No. 4812	1 30
2 iron sand baths, 6″ deep form, E. & A. No. 4555	44
1 spatula, 4″, E. & A. No. 4643	25
1 spatula, 6″, E. & A. No. 4643	35
1 spatula, 8″, E. & A. No. 4643	55
3 clay triangles, small, to fit R. B. crucibles, No. 0, E. & A. No. 4965	25
3 clay triangles, large, to support porcelain evaporating dishes, E. & A. No. 4965	25
1 brass mold for flow test [1]	1 25
3 brass flow plates [1]	1 65
1 New York Testing Laboratory-Seebach drying oven (Hauck-Seebach Co., 291 Essex Street, Brooklyn, New York.)	25 00
1 doz. crystallizing dishes, straight sides, 2¼″ diameter, E. & A. No. 2960	1 68

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[1] New York Testing Laboratory, Maurer, N. J.

2	chemical thermometers, 50-600° F., gas filled, style No. 4881	$5 00
½	doz. camel's hair brushes, large size, E. & A. No. 2943	18
1	New York State Board of Health oil tester with Bunsen burner, E. & A. No. 4160	8 00
½	doz. beakers, 600 cc., 115 mm. high and 85 mm. diameter, E. & A. No. 3872	1 80
1	foot blower, small, E. & A. No. 2308	4 00
¼	pound glass tubing, $\frac{3}{16}$″ diameter.	15
¼	“ glass rod, $\frac{1}{8}$″ diameter	15
1	washing bottle, 1 quart, E. & A. No. 7181	75
50	pounds carbon disulphide, at 10 cents	5 00
5	gallons 88° naphtha, at 20 cents	1 00
1	piece rubber tubing, $\frac{5}{16}$″, E. & A. No. 4540	2 00
1	gross 2-oz. flat tin boxes, E. & A. No. 2482	1 38
		$176 15

The prices given are list, and an estimate should be requested before placing an order, as discounts are given.

The use of the above apparatus has been described in the methods. The Primus burner is the most convenient one at points where gas is not available, as it burns kerosene and is kept clean more easily than the Barthel burner, which burns benzine, 62° Beaumé naphtha.

With the preceding outfit in the hands of a clever yard-foreman or assistant a contractor or a city official should be able, following the methods which have been described, to control accurately the work under his direction.

APPENDIX.

As a type of modern asphalt paving specifications, those of Kansas City, Mo., for 1907, are appended for the information of the reader. As this book goes to press modified specifications are in course of preparation in Kansas City, Mo.

BINDER COURSE.

Upon the base of cement concrete there shall be laid a binder course of asphaltic concrete which, when ultimately compressed by rolling, shall have an average thickness of........(......) inches, and shall be composed and laid as follows: The Binder Course shall consist principally of clean broken stone, which shall pass through a one (1) inch screen. To this stone shall be added well graded sand, or reduced old asphaltic surface mixture (which consists principally of sand) in a sufficient quantity to fill the voids between the stone when laid in mass. The old Asphaltic Surface mixture used in the binder course before being used shall be reduced by being thoroughly disintegrated. To the materials just described shall be added a sufficient quantity of asphaltic cement to thoroughly coat each particle of the composition.

The Asphaltic Cement to be used in the Binder Course shall be composed of a refined asphalt fluxed with a heavy petroleum oil or liquid asphalt. This asphaltic cement shall be composed of such materials as will fulfill the chemical and physical tests required of the asphaltic cement for the Asphalt Wearing Surface.

These component materials shall be combined and mixed while hot by machinery in such proportions that the percentage of bitumen in the binder when laid shall approximately be from 3 per cent to 6 per cent by weight of the total mixture, and such that the aggregate mass shall, when laid and rolled, form a dense compact asphaltic concrete suitable and capable of sustaining an asphalt wearing surface without vibration. The mixture thus prepared shall be spread upon the street base with rakes while in a hot plastic condition, and shall be rammed and rolled until it forms a compact and thoroughly bonded binder course of the required thickness, and its top surface shall be approximately parallel with the completed surface of the pavement.

The binder course shall not be laid upon the concrete base until the expiration of at least ten (10) days in case Natural Cement Concrete is used, or until the expiration of at least five (5) days in case Portland Cement Concrete is used, and then only when the Engineer is satisfied that the concrete has set sufficiently hard to bear the weight of a ten ton roller.

The surface of the concrete foundation shall be swept clean and shall be dry during the laying of the binder, which shall not come in contact with moist or frozen surfaces. No traffic on the binder of horses or vehicles is to take place except such as is required to lay the asphalt pavement surface layer thereon. The traffic then necessary shall in no way injure the Binder. The surface of the Binder must be kept clean at all times and in perfect condition, so as to facilitate the adhesion of the asphalt pavement when laid upon it.

ASPHALT WEARING SURFACE.

The wearing surface shall be laid upon the binder course and, when thoroughly compressed, shall have an average thickness of........(......) inches. The wearing surface shall consist of a uniform mixture of asphaltic cement, sand and a mineral filler, but the asphaltic cement and mineral filler may be used without separation and in their natural state of combination or mixture.

The asphaltic cement, when considered apart from the mineral matter, shall have the following characteristics:

It shall be free from water or decomposition products.

The various hydrocarbons composing it shall be present in homogeneous solution, no oily or granular character being present.

PENETRATION.—It must, when tested at 77 deg. Fahrenheit, have a penetration of from 3 to 9 millimeters when tested for five seconds with a No. 2 needle weighted with 100 grams, according to the nature of the asphalt and the conditions under which it is employed. It must not be so susceptible to changes of temperature that if at 32 deg. Fahrenheit it shows a hardness indicated by 1 millimeter penetration, at 115 deg. Fahrenheit it will not be so soft as to give more than 35 millimeters penetration, using the above method of testing.

Twenty (20) grams of it shall not lose more than four (4) per cent in weight upon being maintained at a uniform temperature of 325 deg. Fahrenheit for seven (7) hours in a cylindrical vessel two and one-half (2½) inches in diameter by two (2) inches high.

Twenty (20) grams of it shall not lose more than eight and one-half (8½) per cent upon being maintained at a uniform temperature of 400 deg.

Fahrenheit for seven (7) hours in a cylindrical vessel two and one-half (2½) inches in diameter by two (2) inches high.

It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least ninety-five (95) per cent.

It shall not contain of carbonaceous matter insoluble in chemically pure carbon disulphide, air temperature, more than four and one-half (4½) per cent.

It shall be soluble in 87 deg. Beaumé petroleum naphtha, air temperature, to the extent of not less than sixty-five (65) per cent and not more than eighty (80) per cent.

Its solubility in carbon tetrachloride shall not be more than one and one-half (1½) per cent less than its solubility in carbon disulphide—both tests being made at air temperature.

It shall show of fixed carbon not more than fifteen (15) per cent.

It shall show a flashing point (New York State Closed Oil Tester) of more than 350 deg. Fahrenheit.

It shall not contain more than three (3) per cent of paraffine scale, the Holde method of determining paraffine scale being used.

Use.—The bitumen entering into the composition shall have been in use in the street paving industry under conditions similar to those contemplated in this contract, at least four (4) years prior to the letting of this contract. The asphaltic cement shall constitute not less than nine and one-half (9½), nor more than thirteen (13) per cent of the surface mixture.

Mixing.—While the ingredients of the asphalt wearing surface are being mixed, and at the time it is being taken from the mixer for use, the paving composition must be thoroughly agitated at a temperature of between 275 deg. and 330 deg. Fahrenheit, and if any part of it settles, it must be again thoroughly agitated before being used.

The characteristics of this material and the tests herein required to be complied with are to be met at the time of making and laying the pavement. It is recognized that its properties change somewhat upon being exposed to weather and street traffic.

The asphaltic cement used under this contract must not be materially changed as to the brands, kinds, proportions and qualities of the ingredients of the mixture during the progress of the work.

The materials, the machinery, testing apparatus and the works of the Contractor shall at all times between the date of the contract for the work and the completion of the work, be open to inspection of the City Engineer for the purpose of enabling him to determine whether the requirements of these specifications are being complied with. No asphaltic cement injured by heating, or otherwise, will be permitted to go into the work.

Sand.—The sand must be clean and sharp and shall not be of uniform size, but various percentages shall pass sieves of the following square mesh per linear inch: 200, 100, 80, 50, 40, 30, 20, and 10.

It shall be present in the surface mixture to such an extent that not less than three (3) per cent nor more than eight (8) per cent of such surface mixture shall consist of sand passing a 200 mesh sieve; that not less than fifteen (15) per cent nor more than thirty-two (32) per cent shall pass an 80 and be retained by a 200 mesh sieve; that not less than twenty-five (25) per cent nor more than forty-five (45) per cent shall pass a 40 and be retained by an 80 mesh sieve; that not less than ten (10) per cent nor more than thirty (30) per cent shall pass a 10 and be retained by a 40 mesh sieve.

The mineral particles, including limestone or Portland cement, which when thoroughly mixed by air blast, or otherwise, with distilled water at a temperature of 77 deg. Fahrenheit, will subside in fifteen (15) seconds, is by the terms of this contract regarded as sand. This test shall be conducted in a beaker about six (6) inches high and nearly full of the water and material to be tested.

FILLER.—The filler shall be composed of mineral particles so small that when they are thoroughly agitated with distilled water at a temperature of 77 deg. Fahrenheit, by means of an air blast, or otherwise, they will not subside in fifteen (15) seconds, but can be poured off with the water after a lapse of fifteen (15) seconds from the time agitation ceased. This test is to be carried out in a beaker as described in the preceding paragraph. Such fine mineral matter shall be insoluble in water and shall by the terms of this contract be known as filler and shall constitute not less than four (4) per cent nor more than seven (7) per cent of the total wearing surface.

The exact proportions of all constituents of the wearing surface to be determined by the Contractor shall be subject to the approval of the City Engineer.

The sand and asphaltic cement shall be heated separately to about 330 deg. Fahrenheit. The mineral filler will be mixed while cold with the sand while hot, and which shall have been heated to about 330 deg. Fahrenheit, and then this composition shall be mixed with the asphaltic cement at the temperature stated, in such a manner and with such apparatus as to effect a thoroughly homogeneous mixture.

Samples of all material entering into the composition of the pavement shall be supplied to the City Engineer, when required, in suitable tin boxes and cans, and the Contractor, when required, shall give to the Engineer a written statement of the date and geographical source of all crude or other materials from which the refined asphaltum is made, and proportions of each, also per cent of pure bitumen contained therein. The City Engineer, or his representatives, shall have access to all branches of the works at any time. He, or his representatives, shall inspect the material furnished and work done upon the asphalt pavement, and have power to enforce all requirements of specifications. He shall at all times have access to the works and laboratories of the Contractors, and shall have privilege to take samples from such works, or from material upon the streets, as may be deemed advisable or necessary for testing purposes.

It shall be the duty of the Contractor, when performing work under the contract, to furnish complete detailed analyses of the ingredients of the paving mixture to the City Engineer, whenever requested by him so to do.

The paving mixture prepared in the manner thus indicated shall be brought to the ground in carts or wagons at a temperature of not less than 250 deg. nor more than 350 deg. Fahrenheit. If the temperature of the air is less than 60 deg. Fahrenheit, the Contractor must provide canvas covers for use in transit. It will then be thoroughly spread by means of hot rakes in such a manner as to give a uniform and regular grade, so that after having reached its ultimate compression it shall have a thickness shown on the plans and required in the specifications. This depth shall be constantly tested by means of gauges. The surface shall then be compressed by a small steam-roller or hand-roller, after which a small amount of Hydraulic Cement will be spread over it, and it will then be thoroughly compressed by a steam-roller weighing not less than two hundred and fifty (250) pounds to the inch run, the rolling being continued for not less than five (5) hours for every thousand square yards of surface.

ASPHALTIC WEARING SURFACE.—The acceptance of said work by the City Engineer after its completion, shall be conclusive of the fact that the provisions hereof under the above heading, "Asphalt Wearing Surface," has been complied with.

REPAIRS.—All repairs of asphalt pavement required to be made by the Contractor during the guarantee period shall be made with mixtures similar and equal to and laid in the manner of those described above.

COMPARISON OF ACTUAL SPECIFIC GRAVITY AND DEGREES BEAUMÉ HYDROMETER.

For liquids lighter than water, specific gravity $= \frac{140}{130 + ° \text{Bé}}$ at 60° F.

° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.
10.0	1.0000	14.0	0.9722	18.0	0.9459	22.0	0.9211
.1	0.9993	.1	0.9715	.1	0.9453	.1	0.9204
.2	0.9986	.2	0.9709	.2	0.9447	.2	0.9198
.3	0.9979	.3	0.9702	.3	0.9440	.3	0.9192
.4	0.9972	.4	0.9695	.4	0.9434	.4	0.9186
.5	0.9964	.5	0.9689	.5	0.9428	.5	0.9180
.6	0.9957	.6	0.9682	.6	0.9421	.6	0.9174
.7	0.9950	.7	0.9675	.7	0.9415	.7	0.9168
.8	0.9943	.8	0.9669	.8	0.9409	.8	0.9162
.9	0.9936	.9	0.9662	.9	0.9402	.9	0.9156
11.0	0.9929	15.0	0.9655	19.0	0.9396	23.0	0.9150
.1	0.9922	.1	0.9649	.1	0.9390	.1	0.9144
.2	0.9915	.2	0.9642	.2	0.9383	.2	0.9138
.3	0.9908	.3	0.9635	.3	0.9377	.3	0.9132
.4	0.9901	.4	0.9629	.4	0.9371	.4	0.9126
.5	0.9894	.5	0.9622	.5	0.9365	.5	0.9121
.6	0.9887	.6	0.9615	.6	0.9358	.6	0.9115
.7	0.9880	.7	0.9609	.7	0.9352	.7	0.9109
.8	0.9873	.8	0.9602	.8	0.9346	.8	0.9103
.9	0.9866	.9	0.9596	.9	0.9340	.9	0.9097
12.0	0.9859	16.0	0.9589	20.0	0.9333	24.0	0.9091
.1	0.9852	.1	0.9582	.1	0.9327	.1	0.9085
.2	0.9845	.2	0.9576	.2	0.9321	.2	0.9079
.3	0.9838	.3	0.9569	.3	0.9315	.3	0.9073
.4	0.9831	.4	0.9563	.4	0.9309	.4	0.9067
.5	0.9825	.5	0.9556	.5	0.9302	.5	0.9061
.6	0.9818	.6	0.9550	.6	0.9296	.6	0.9056
.7	0.9811	.7	0.9543	.7	0.9290	.7	0.9050
.8	0.9804	.8	0.9537	.8	0.9284	.8	0.9044
.9	0.9797	.9	0.9530	.9	0.9278	.9	0.9038
13.0	0.9790	17.0	0.9524	21.0	0.9272	25.0	0.9032
.1	0.9783	.1	0.9517	.1	0.9265	.1	0.9026
.2	0.9777	.2	0.9511	.2	0.9259	.2	0.9021
.3	0.9770	.3	0.9504	.3	0.9253	.3	0.9015
.4	0.9763	.4	0.9498	.4	0.9247	.4	0.9009
.5	0.9756	.5	0.9492	.5	0.9241	.5	0.9003
.6	0.9749	.6	0.9485	.6	0.9235	.6	0.8997
.7	0.9743	.7	0.9479	.7	0.9229	.7	0.8992
.8	0.9736	.8	0.9472	.8	0.9223	.8	0.8986
.9	0.9729	.9	0.9466	.9	0.9217	.9	0.8980

COMPARISON OF ACTUAL SPECIFIC GRAVITY AND DEGREES BEAUMÉ HYDROMETER—*Continued.*

° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.
26.0	0.8974	31.0	0.8696	36.0	0.8434	41.0	0.8187
.1	0.8969	.1	0.8690	.1	0.8429	.1	0.8182
.2	0.8963	.2	0.8685	.2	0.8424	.2	0.8178
.3	0.8957	.3	0.8679	.3	0.8419	.3	0.8173
.4	0.8951	.4	0.8674	.4	0.8413	.4	0.8168
.5	0.8946	.5	0.8669	.5	0.8408	.5	0.8163
.6	0.8940	.6	0.8663	.6	0.8403	.6	0.8159
.7	0.8934	.7	0.8658	.7	0.8398	.7	0.8154
.8	0.8929	.8	0.8653	.8	0.8393	.8	0.8149
.9	0.8923	.9	0.8647	.9	0.8388	.9	0.8144
27.0	0.8917	32.0	0.8642	37.0	0.8383	42.0	0.8140
.1	0.8912	.1	0.8637	.1	0.8378	.1	0.8135
.2	0.8906	.2	0.8631	.2	0.8373	.2	0.8130
.3	0.8900	.3	0.8626	.3	0.8368	.3	0.8125
.4	0.8895	.4	0.8621	.4	0.8363	.4	0.8121
.5	0.8889	.5	0.8615	.5	0.8358	.5	0.8116
.6	0.8883	.6	0.8610	.6	0.8353	.6	0.8111
.7	0.8878	.7	0.8605	.7	0.8348	.7	0.8107
.8	0.8872	.8	0.8600	.8	0.8343	.8	0.8102
.9	0.8866	.9	0.8594	.9	0.8338	.9	0.8097
28.0	0.8861	33.0	0.8589	38.0	0.8333	43.0	0.8092
.1	0.8855	.1	0.8584	.1	0.8328	.1	0.8088
.2	0.8850	.2	0.8578	.2	0.8323	.2	0.8083
.3	0.8844	.3	0.8573	.3	0.8318	.3	0.8078
.4	0.8838	.4	0.8568	.4	0.8314	.4	0.8074
.5	0.8833	.5	0.8563	.5	0.8309	.5	0.8069
.6	0.8827	.6	0.8557	.6	0.8304	.6	0.8065
.7	0.8822	.7	0.8552	.7	0.8299	.7	0.8060
.8	0.8816	.8	0.8547	.8	0.8294	.8	0.8055
.9	0.8811	.9	0.8542	.9	0.8289	.9	0.8051
29.0	0.8805	34.0	0.8537	39.0	0.8284	44.0	0.8046
.1	0.8799	.1	0.8531	.1	0.8279	.1	0.8041
.2	0.8794	.2	0.8526	.2	0.8274	.2	0.8037
.3	0.8788	.3	0.8521	.3	0.8269	.3	0.8032
.4	0.8783	.4	0.8516	.4	0.8264	.4	0.8028
.5	0.8777	.5	0.8511	.5	0.8260	.5	0.8023
.6	0.8772	.6	0.8505	.6	0.8255	.6	0.8018
.7	0.8766	.7	0.8500	.7	0.8250	.7	0.8014
.8	0.8761	.8	0.8495	.8	0.8245	.8	0.8009
.9	0.8755	.9	0.8490	.9	0.8240	.9	0.8005
30.0	0.8750	35.0	0.8485	40.0	0.8235	45.0	0.8000
.1	0.8745	.1	0.8480	.1	0.8230	.1	0.7995
.2	0.8739	.2	0.8475	.2	0.8226	.2	0.7991
.3	0.8734	.3	0.8469	.3	0.8221	.3	0.7986
.4	0.8728	.4	0.8464	.4	0.8216	.4	0.7982
.5	0.8723	.5	0.8459	.5	0.8211	.5	0.7977
.6	0.8717	.6	0.8454	.6	0.8206	.6	0.7973
.7	0.8712	.7	0.8449	.7	0.8202	.7	0.7968
.8	0.8706	.8	0.8444	.8	0.8197	.8	0.7964
.9	0.8701	.9	0.8439	.9	0.8192	.9	0.7959

COMPARISON OF ACTUAL SPECIFIC GRAVITY AND DEGREES BEAUMÉ HYDROMETER—*Continued.*

° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.
46.0	0.7955	51.0	0.7735	56.0	0.7527	61.0	0.7330
.1	0.7950	.1	0.7731	.1	0.7523	.1	0.7326
.2	0.7946	.2	0.7726	.2	0.7519	.2	0.7322
.3	0.7941	.3	0.7722	.3	0.7515	.3	0.7318
.4	0.7937	.4	0.7718	.4	0.7511	.4	0.7315
.5	0.7932	.5	0.7713	.5	0.7507	.5	0.7311
.6	0.7928	.6	0.7709	.6	0.7503	.6	0.7307
.7	0.7923	.7	0.7705	.7	0.7499	.7	0.7303
.8	0.7919	.8	0.7701	.8	0.7495	.8	0.7299
.9	0.7914	.9	0.7697	.9	0.7491	.9	0.7295
47.0	0.7910	52.0	0.7692	57.0	0.7487	62.0	0.7292
.1	0.7905	.1	0.7688	.1	0.7483	.1	0.7288
.2	0.7901	.2	0.7684	.2	0.7479	.2	0.7284
.3	0.7896	.3	0.7680	.3	0.7475	.3	0.7280
.4	0.7892	.4	0.7675	.4	0.7471	.4	0.7277
.5	0.7887	.5	0.7671	.5	0.7467	.5	0.7273
.6	0.7883	.6	0.7667	.6	0.7463	.6	0.7269
.7	0.7878	.7	0.7663	.7	0.7459	.7	0.7265
.8	0.7874	.8	0.7659	.8	0.7455	.8	0.7261
.9	0.7870	.9	0.7654	.9	0.7451	.9	0.7258
48.0	0.7865	53.0	0.7650	58.0	0.7447	63.0	0.7254
.1	0.7861	.1	0.7646	.1	0.7443	.1	0.7250
.2	0.7856	.2	0.7642	.2	0.7439	.2	0.7246
.3	0.7852	.3	0.7638	.3	0.7435	.3	0.7243
.4	0.7848	.4	0.7634	.4	0.7431	.4	0.7239
.5	0.7843	.5	0.7629	.5	0.7427	.5	0.7235
.6	0.7839	.6	0.7625	.6	0.7423	.6	0.7231
.7	0.7834	.7	0.7621	.7	0.7419	.7	0.7228
.8	0.7830	.8	0.7617	.8	0.7415	.8	0.7224
.9	0.7826	.9	0.7613	.9	0.7411	.9	0.7220
49.0	0.7821	54.0	0.7609	59.0	0.7407	64.0	0.7216
.1	0.7817	.1	0.7605	.1	0.7403	.1	0.7213
.2	0.7812	.2	0.7600	.2	0.7400	.2	0.7209
.3	0.7808	.3	0.7596	.3	0.7396	.3	0.7205
.4	0.7804	.4	0.7592	.4	0.7392	.4	0.7202
.5	0.7799	.5	0.7588	.5	0.7388	.5	0.7198
.6	0.7795	.6	0.7584	.6	0.7384	.6	0.7194
.7	0.7791	.7	0.7580	.7	0.7380	.7	0.7191
.8	0.7786	.8	0.7576	.8	0.7376	.8	0.7187
.9	0.7782	.9	0.7572	.9	0.7372	.9	0.7183
50.0	0.7778	55.0	0.7568	60.0	0.7368	65.0	0.7179
.1	0.7773	.1	0.7563	.1	0.7365	.1	0.7176
.2	0.7769	.2	0.7559	.2	0.7361	.2	0.7172
.3	0.7765	.3	0.7555	.3	0.7357	.3	0.7168
.4	0.7761	.4	0.7551	.4	0.7353	.4	0.7165
.5	0.7756	.5	0.7547	.5	0.7349	.5	0.7161
.6	0.7752	.6	0.7543	.6	0.7345	.6	0.7157
.7	0.7748	.7	0.7539	.7	0.7341	.7	0.7154
.8	0.7743	.8	0.7535	.8	0.7338	.8	0.7150
.9	0.7739	.9	0.7531	.9	0.7334	.9	0.7147

COMPARISON OF ACTUAL SPECIFIC GRAVITY AND DEGREES BEAUMÉ HYDROMETER—*Continued.*

° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.	° Bé.	Sp. Gr.
66.0	0.7143	70.0	0.7000	74.0	0.6863	78.0	0.6731
.1	0.7139	.1	0.6997	.1	0.6859	.1	0.6728
.2	0.7136	.2	0.6993	.2	0.6856	.2	0.6724
.3	0.7132	.3	0.6990	.3	0.6853	.3	0.6721
.4	0.7128	.4	0.6986	.4	0.6849	.4	0.6718
.5	0.7125	.5	0.6983	.5	0.6846	.5	0.6715
.6	0.7121	.6	0.6979	.6	0.6843	.6	0.6711
.7	0.7117	.7	0.6976	.7	0.6839	.7	0.6708
.8	0.7114	.8	0.6972	.8	0.6836	.8	0.6705
.9	0.7110	.9	0.6969	.9	0.6833	.9	0.6702
67.0	0.7107	71.0	0.6965	75.0	0.6829	79.0	0.6699
.1	0.7103	.1	0.6962	.1	0.6826	.1	0.6695
.2	0.7099	.2	0.6958	.2	0.6823	.2	0.6692
.3	0.7096	.3	0.6955	.3	0.6819	.3	0.6689
.4	0.7092	.4	0.6951	.4	0.6816	.4	0.6686
.5	0.7089	.5	0.6948	.5	0.6813	.5	0.6683
.6	0.7085	.6	0.6944	.6	0.6809	.6	0.6679
.7	0.7081	.7	0.6941	.7	0.6806	.7	0.6676
.8	0.7078	.8	0.6938	.8	0.6803	.8	0.6673
.9	0.7074	.9	0.6934	.9	0.6799	.9	0.6670
68.0	0.7071	72.0	0.6931	76.0	0.6796	80.0	0.6667
.1	0.7067	.1	0.6927	.1	0.6793		
.2	0.7064	.2	0.6924	.2	0.6790		
.3	0.7060	.3	0.6920	.3	0.6786		
.4	0.7056	.4	0.6917	.4	0.6783		
.5	0.7053	.5	0.6914	.5	0.6780		
.6	0.7049	.6	0.6910	.6	0.6776		
.7	0.7046	.7	0.6907	.7	0.6773		
.8	0.7042	.8	0.6903	.8	0.6770		
.9	0.7039	.9	0.6900	.9	0.6767		
69.0	0.7035	73.0	0.6897	77.0	0.6763		
.1	0.7032	.1	0.6893	.1	0.6760		
.2	0.7028	.2	0.6890	.2	0.6757		
.3	0.7025	.3	0.6886	.3	0.6753		
.4	0.7021	.4	0.6883	.4	0.6750		
.5	0.7018	.5	0.6880	.5	0.6747		
.6	0.7014	.6	0.6876	.6	0.6744		
.7	0.7011	.7	0.6873	.7	0.6740		
.8	0.7007	.8	0.6869	.8	0.6737		
.9	0.7004	.9	0.6866	.9	0.6734		

FACTORS.

Metric to U. S. Standard Weight, Measures, etc.

1 Milligram = .01543 Grain
1 Gram = .03572 Ounce (Av'd.)
1 Kilo = 2.205 Pounds (Av'd.)

1 Grain = 64.799 Milligrams
1 Ounce (Av'd.) = 28.3495 Grams
1 Pound = .4536 Kilogram

1 Centimeter = .3937 Inch
1 Meter = 3.281 Feet
1 Meter = 1.0936 Yards
1 Kilometer = .6214 Statute mile

1 Inch = 2.540 Centimeters
1 Foot = .3048 Meter
1 Yard = .9144 Meter
1 Statute mile = 1.6093 Kilometers

1 Liter = 1.0567 Quarts
1 Liter = .2647 Gallon
1 Cubic meter = 264.1705 Gallons

1 Quart = .9464 Liter
1 Gallon = 3.7854 Liters
1 Gallon = .00379 Cubic meter

1 Square centimeter = .1550 Square inch
1 Square meter = 10.764 Square Feet
1 Square meter = 1.196 Yards
1 Square kilometer = .3861 Mile

1 Square inch = 6.4516 Square centimeters
1 Square foot = .0929 Square meter
1 Square yard = .8361 Square meter
1 Square mile = 2.59 Square kilometers

1 Cubic centimeter = .06102 Cubic inch
1 Cubic meter = 35.31445 Cubic feet
1 Cubic meter = 1.3079 Cubic yards

1 Cubic inch = 16.3872 Cubic centimeters
1 Cubic foot = .02832 Cubic meter
1 Cubic yard = .76456 Cubic meter

1 Kilogram per square centimeter = 14.2234 Pounds per square inch
1 Kilogram per square meter = .20482 Pound per square foot
1 Kilogram per cubic meter = .06243 Pound per cubic foot

1 Pound per square inch = .07031 Kilo per square centimeter
1 Pound per square foot = 4.8824 Kilos per square meter
1 Pound per cubic foot = 16.0184 Kilos per cubic meter

1 Gram per 100 cubic centimeter = .624 Pound per cubic foot

TEMPERATURES CENTIGRADE AND FAHRENHEIT.

C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °
−29	−20.2	+39	+102.2	+107	+224.6	+175	+347.0	+243	+469.4
28	18.4	40	104.0	108	226.4	176	348.8	244	471.2
27	16.6	41	105.8	109	228.2	177	350.6	245	473.0
26	14.8	42	107.6	110	230.0	178	352.4	246	474.8
25	13.0	43	109.4	111	231.8	179	354.2	247	476.6
24	11.2	44	111.2	112	233.6	180	356.0	248	478.4
23	9.4	45	113.0	113	235.4	181	357.8	249	480.2
22	7.6	46	114.8	114	237.2	182	359.6	250	482.0
21	5.8	47	116.6	115	239.0	183	361.4	251	483.8
20	4.0	48	118.4	116	240.8	184	363.2	252	485.6
19	2.2	49	120.2	117	242.6	185	365.0	253	487.4
18	0.4	50	122.0	118	244.4	186	366.8	254	489.2
17	+ 1.4	51	123.8	119	246.2	187	368.6	255	491.0
16	3.2	52	125.6	120	248.0	188	370.4	256	492.8
15	5.0	53	127.4	121	249.8	189	372.2	257	494.6
14	6.8	54	129.2	122	251.6	190	374.0	258	496.4
13	8.6	55	131.0	123	253.4	191	375.8	259	498.2
12	10.4	56	132.8	124	255.2	192	377.6	260	500.0
11	12.2	57	134.6	125	257.0	193	379.4	261	501.8
10	14.0	58	136.4	126	258.8	194	381.2	262	503.6
9	15.8	59	138.2	127	260.6	195	383.0	263	505.4
8	17.6	60	140.0	128	262.4	196	384.8	264	507.2
7	19.4	61	141.8	129	264.2	197	386.6	265	509.0
6	21.2	62	143.6	130	266.0	198	388.4	266	510.8
5	23.0	63	145.4	131	267.8	199	390.2	267	512.6
4	24.8	64	147.2	132	269.6	200	392.0	268	514.4
3	26.6	65	149.0	133	271.4	201	393.8	269	516.2
2	28.4	66	150.8	134	273.2	202	395.6	270	518.0
1	30.2	67	152.6	135	275.0	203	397.4	271	519.8
0	32.0	68	154.4	136	276.8	204	399.2	272	521.6
+ 1	33.8	69	156.2	137	278.6	205	401.0	273	523.4
2	35.6	70	158.0	138	280.4	206	402.8	274	525.2
3	37.4	71	159.8	139	282.2	207	404.6	275	527.0
4	39.2	72	161.6	140	284.0	208	406.4	276	528.8
5	41.0	73	163.4	141	285.8	209	408.2	277	530.6
6	42.8	74	165.2	142	287.6	210	410.0	278	532.4
7	44.6	75	167.0	143	289.4	211	411.8	279	534.2
8	46.4	76	168.8	144	291.2	212	413.6	280	536.0
9	48.2	77	170.6	145	293.0	213	415.4	281	537.8
10	50.0	78	172.4	146	294.8	214	417.2	282	539.6
11	51.8	79	174.2	147	296.6	215	419.0	283	541.4
12	53.6	80	176.0	148	298.4	216	420.8	284	543.2
13	55.4	81	177.8	149	300.2	217	422.6	285	545.0
14	57.2	82	179.6	150	302.0	218	424.4	286	546.8
15	59.0	83	181.4	151	303.8	219	426.2	287	548.6
16	60.8	84	183.2	152	305.6	220	428.0	288	550.4
17	62.6	85	185.0	153	307.4	221	429.8	289	552.2
18	64.4	86	186.8	154	309.2	222	431.6	290	554.0
19	66.2	87	188.6	155	311.0	223	433.4	300	572.0
20	68.0	88	190.4	156	312.8	224	435.2	310	590.0
21	69.8	89	192.2	157	314.6	225	437.0	320	608.0
22	71.6	90	194.0	158	316.4	226	438.8	330	626.0
23	73.4	91	195.8	159	318.2	227	440.6	340	644.0
24	75.2	92	197.6	160	320.0	228	442.4	350	662.0
25	77.0	93	199.4	161	321.8	229	444.2	360	680.0
26	78.8	94	201.2	162	323.6	230	446.0	370	698.0
27	80.6	95	203.0	163	325.4	231	447.8	380	716.0
28	82.4	96	204.8	164	327.2	232	449.6	390	734.0
29	84.2	97	206.6	165	329.0	233	451.4	400	752.0
30	86.0	98	208.4	166	330.8	234	453.2	410	770.0
31	87.8	99	210.2	167	332.6	235	455.0	420	788.0
32	89.6	100	212.0	168	334.4	236	456.8	430	806.0
33	91.4	101	213.8	169	336.2	237	458.6	440	824.0
34	93.2	102	215.6	170	338.0	238	460.4	450	842.0
35	95.0	103	217.4	171	339.8	239	462.2	460	860.0
36	96.8	104	219.2	172	341.6	240	464.0	470	878.0
37	98.6	105	221.0	173	343.4	241	465.8	480	896.0
38	100.4	106	222.4	174	345.2	242	467.6	490	914.0
								500	932.0

CONCLUSION.

In closing these pages the author may say that the statements which have been made are all founded on his own experience, and that the data which have been presented are the result of examinations and investigations carried on in his own laboratory, except where it is stated to the contrary. The conclusions which have been drawn, of course, involve his judgment as well as his experience, but they have been based on practical results rather than upon theories, as the latter often do not lead to success in the construction of asphalt surfaces or to a satisfactory explanation of defective work.

An attempt has been made to gather together such information as is available in regard to the asphalt-paving industry and asphalt pavements in general, in a form which will appeal to and be understood by the practical man, the engineer, the asphalt expert and, finally, in certain chapters, to the citizen at large. If the result proves in any way successful and the character of the asphalt pavements which are constructed in the future are in any way improved thereby, it will be a sufficient reward for the labor involved in bringing out this book.

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